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SECTION ACROSS COMMERCIAL QUARRY, CRESTMORE, CALIFORNIA

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ABSTRACT

At Crestmore, in southern California, crystalline limestone is bordered by large and varied assemblages of contact metamorphic minerals. Renewed quarrying has re-exposed the critical contacts of the limestone with intrusive quartz monzonite porphyry and pegmatites. The number of named minerals found in all the rocks at the locality has now reached 109, including 2 probable duplications and 5 other doubtful determinations. There are 13 or 14 additional new or undetermined species, making a total of about 120 known minerals. In the present paper there are shown the occurrences of the rocks and minerals with reference to a map and a section across Commercial quarry, supplemented by a corresponding section in the adjacent Wet Weather quarry.

The quartz monzonite porphyry grades into pegmatite, and both the porphyry and the fairly numerous pegmatitic dikes and irregular pegmatitic patches are closely associated with the silicate contact rock. The latter is rather certainly the result of additive metamorphism of the non-siliceous limestone and predazzite. Thus far it has not been found possible to distinguish clearly more than one zone or facies in the contact rock, even though diopside, wollastonite, monticellite, spurrite and merwinite are all present.

INTRODUCTION

The best known mineral locality in California, if not in the whole western United States, is at Crestmore near Riverside, 50 miles east of Los Angeles. Many years ago the Riverside Cement Company began separate excavations for limestone at several places on the twin Crestmore hills,—one on the southwestern or Chino hill and three on the northeastern or Sky Blue hill. Now the various surface and underground operations at these localities have nearly coalesced. The mineralogically more productive excavations are those on Sky Blue hill—the old Commercial quarry and the more active, adjacent Wet Weather and Lone Star quarries.

More than 20 papers have been published concerning Crestmore, beginning with those by Eakle and Rogers in 1914. Crestmore has been a place from which collectors have obtained fine specimens and rare species. Most of the published papers have described the minerals without much attention to their exact mode of geological occurrence. This deficiency has been largely filled by John Daly's excellent report on the "Paragenesis", written in 1931 as a Master's thesis at the California Institute of Technology and published in part in 1935 (19).

Our present study was begun to take advantage of fresh exposures due to the removal of rock from the talus accumulations and from the face of the Commercial quarry in the autumn of 1938. In 1939 and 1940 there has been quarrying for limestone in Lone Star and Wet Weather quarries, and this work continues. We are now placing on record two measured profiles showing the various rocks and some of the minerals which were exposed in 1939–40 in the Commercial and the Wet Weather quarries. We are able to locate many of the older finds with respect to our map and profiles. We are presenting also information concerning the minerals and rocks uncovered in Lone Star quarry, and a revised list of more than 100 Crestmore minerals, an increase of at least 20 over any previous published list.

CRESTMORE ROCKS

General Description

There are exposed at Crestmore crystalline limestone and other metamorphosed sediments, enveloped in and cut by intrusive igneous rocks.

The limestone is coarsely crystalline, with calcite grains usually 3 or 4 mm., and occasionally 15 to 30 mm., in diameter. This rock is similar to that at numerous other localities in the vicinity and in the San Bernardino and eastern San Gabriel mountains (Fig. 1). The age of the limestone is probably Upper Paleozoic, as fossils which have been referred to the Mississippian have been found at two widely separated localities.[1] The limestones that are now found in the vicinity of Riverside are relatively small roof pendants preserved in an enveloping and intrusive quartz diorite or granodiorite, with or without other finer grained intrusives. Quartzite, either pure or micaceous, is commonly associated with the limestone remnants. At several localities extensive suites of contact metamorphic minerals have been developed in the limestones. The contact metamorphic assemblages are much the same at Victoria and other quarries in the city of Riverside, at Crestmore, and at Cascade Canyon in the San Gabriel Mountains. However, most of the rarer Crestmore minerals are not found at the other localities.

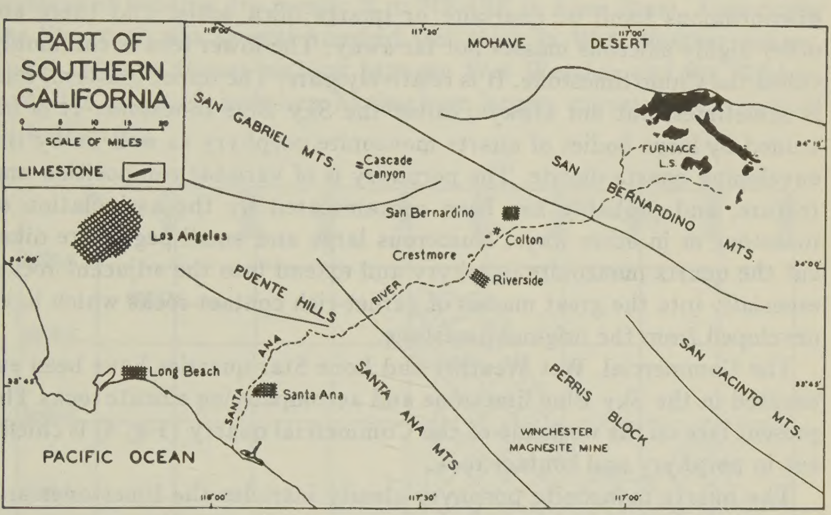

FIG. 1. Index map of a portion of southern California, showing some of the areas of crystalline limestone.

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[1] Woodford, A. O., and Harriss, T. F., Geology of Blackhawk canyon, San Bernardino Mountains, California: *Univ. Calif. Publ. Bull., Dept. Geol. Sci.*, **17**, 265–304 (1928) (Furnace limestone). Webb, R. W., Evidence of the age of a crystalline limestone in Southern California: *Jour. Geol.*, **47**, 198–201 (1939) (Winchester magnesite mine).

At Crestmore the limestone occurs as two irregular, very roughly parallel, lenticular bodies whose principal portions have dips up to 45° E or ENE. The prevalent N or NNW strike conforms to the trend of the Peninsular Range to the south, and is almost perpendicular to that of certain other metamorphic rocks near Riverside, suggesting that this region is one of structural transition to the E-W strikes prevalent at Cascade canyon and elsewhere in the "Transverse" ranges to the north. The lower (western) limestone body at Crestmore is overlain by a thin, discontinuous band of quartzite or quartz mica schist and there are other highly siliceous masses not far away. The lower lens is commonly called the Chino limestone. It is relatively pure. The upper (eastern) lens is sometimes, but not always, called the Sky Blue limestone. It is intruded by large bodies of quartz monzonite porphyry as well as by the enveloping quartz diorite. The porphyry is of variable composition and texture, and probably has been contaminated by the assimilation of limestone or in other ways. Numerous large and small pegmatite dikes cut the quartz monzonite porphyry and extend into the adjacent rocks, especially into the great masses of garnet-rich contact rocks which have developed from the original limestone.

The Commercial, Wet Weather and Lone Star quarries have been excavated in the Sky Blue limestone and accompanying silicate rocks.The present face on the west side of the Commercial quarry (Fig. 4) is chiefly cut in porphyry and contact rock.

The quartz monzonite porphyry clearly intrudes the limestones and contact rocks. The porphyry is probably also younger than the quartz diorite.

Chino Limestone

The Chino Hill limestone of Eakle (4), called Chino quarry limestone by Daly (19), has been well described lithologically by these authors. It is typically composed of bands a few inches or a few feet thick of alternating coarse white crystalline limestone and somewhat yellowish predazzite. Graphite flakes are widely disseminated through the limestone but are far from universal. The brucite in the predazzite is pseudomorphic after octahedral periclase. The grains of brucite are commonly one to two millimeters across and are surrounded by still larger anhedrons of calcite, making a rock which is considerably coarser grained than the type predazzite, but otherwise very similar in appearance.

The Chino limestone lens dips up to 45° east, is at least 2000 feet long, and extends down the dip at least 1200 feet (to sea level). The upper and lower surfaces are both uneven. The maximum thickness has proved to be about 300 feet. Practically the whole original outcrop of the Chino limestone has now been removed by quarrying and mining operations and its site is marked by a glory hole two hundred feet deep in the center.

Sky Blue Limestone

The upper or Sky Blue limestone has an arcuate outcrop, as indicated by the positions of the Lone Star and Wet Weather quarries and the 910-foot level of Commerical quarry (Fig. 3 map). The observable suggestions of bedding dip mostly E or NE (SE in Lone Star). Apparently the limestone was several hundred feet thick in Wet Weather quarry, but it thins to almost nothing between Wet Weather and the 910-foot level, the limestone beds here having been largely converted into contact rock (Fig. 2).

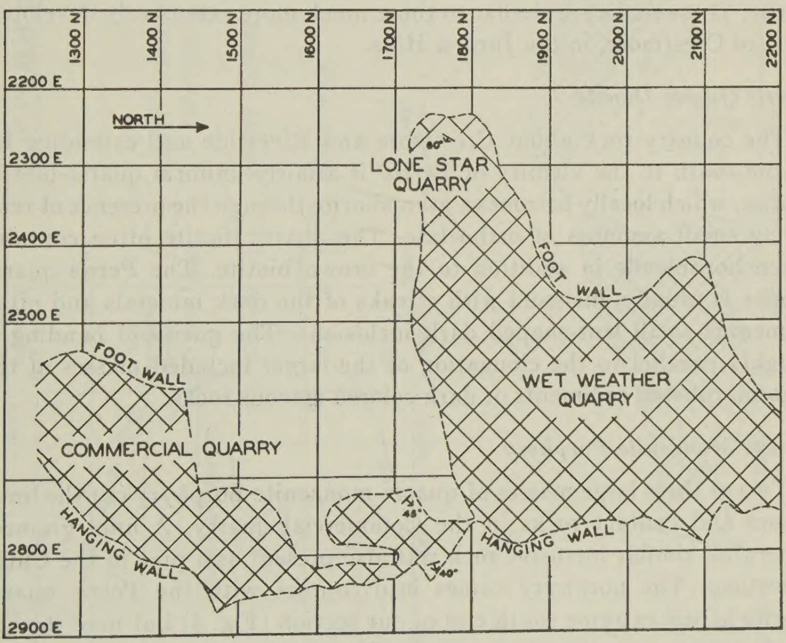

FIG. 2. Sky Blue limestone at 900 feet above sea level. Slightly modified from records of Riverside Cement Co. Map ruled at 100-foot intervals.

The structure of the limestone is uncertain. It may be a nearly isoclinal fold, with a longer E-dipping limb extending south through the 910-foot level, and a shorter SE-dipping limb marked by the shallow, high-level southwest extension of Lone Star quarry (not shown in Fig. 2).

The Sky Blue limestone has two facies, one of which is white like the Chino limestone and locally contains similar yellow predazzite beds. But close to the intrusive quartz monzonite porphyry and its pegmatites, that is, in or near the great masses of contact rock, this limestone has commonly developed a striking sky blue color. Masses of blue rock fifty feet thick are practically pure calcite. Elsewhere patches of the blue limestone, the size of a man's hand, spot the garnet and idocrase-rich contact rock.

This rock was called the Sky Blue quarry limestone by Daly (19).

Quartzite and Schist

Above the Chino limestone, and usually separated from it by a quartz diorite sill, there are commonly a few feet of quartzite and quartz-biotite schist. These rocks are similar to those much more extensively developed west of Crestmore, in the Jurupa Hills.

Perris Quartz Diorite

The country rock about Crestmore and Riverside and extending far to the south to the vicinity of Perris[2] is a fairly uniform quartz-biotite diorite, which locally becomes a granodiorite through the presence of relatively small amounts of orthoclase. The quartz diorite often contains green hornblende in addition to the brown biotite. The Perris quartz diorite is usually gneissoid with streaks of the dark minerals and often numerous small lens-shaped dark inclusions. The gneissoid banding is roughly parallel to the elongation of the larger included masses of the metamorphosed sediments or dark colored igneous rocks.

Quartz Monzonite Porphyry

Two or three large masses of quartz monzonite porphyry cut the limestones and contact rocks in the Commercial quarry. A finer grained, somewhat similar intrusive rock was also present as a pipe in the Chino limestone. The porphyry comes into contact with the Perris quartz diorite at the extreme south end of our section (Fig. 3) but here the age relationships are not entirely certain. The porphyry is probably younger than the quartz diorite, as indicated by Daly (19).

The typical quartz monzonite porphyry is a massive rock which contains about equal quantities of orthoclase and oligoclase, with abundant quartz and scattered grains and aggregates of pale pyroxene. The phenocrysts of feldspar are commonly one or two millimeters in diameter and the individual grains of pyroxene somewhat smaller. The feldspars are

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[2] Dudley, Paul H., Geology of a portion of the Perris block, southern California; *Calif. Jour. Mines and Geol.*, **31**, 487-506 (1936).

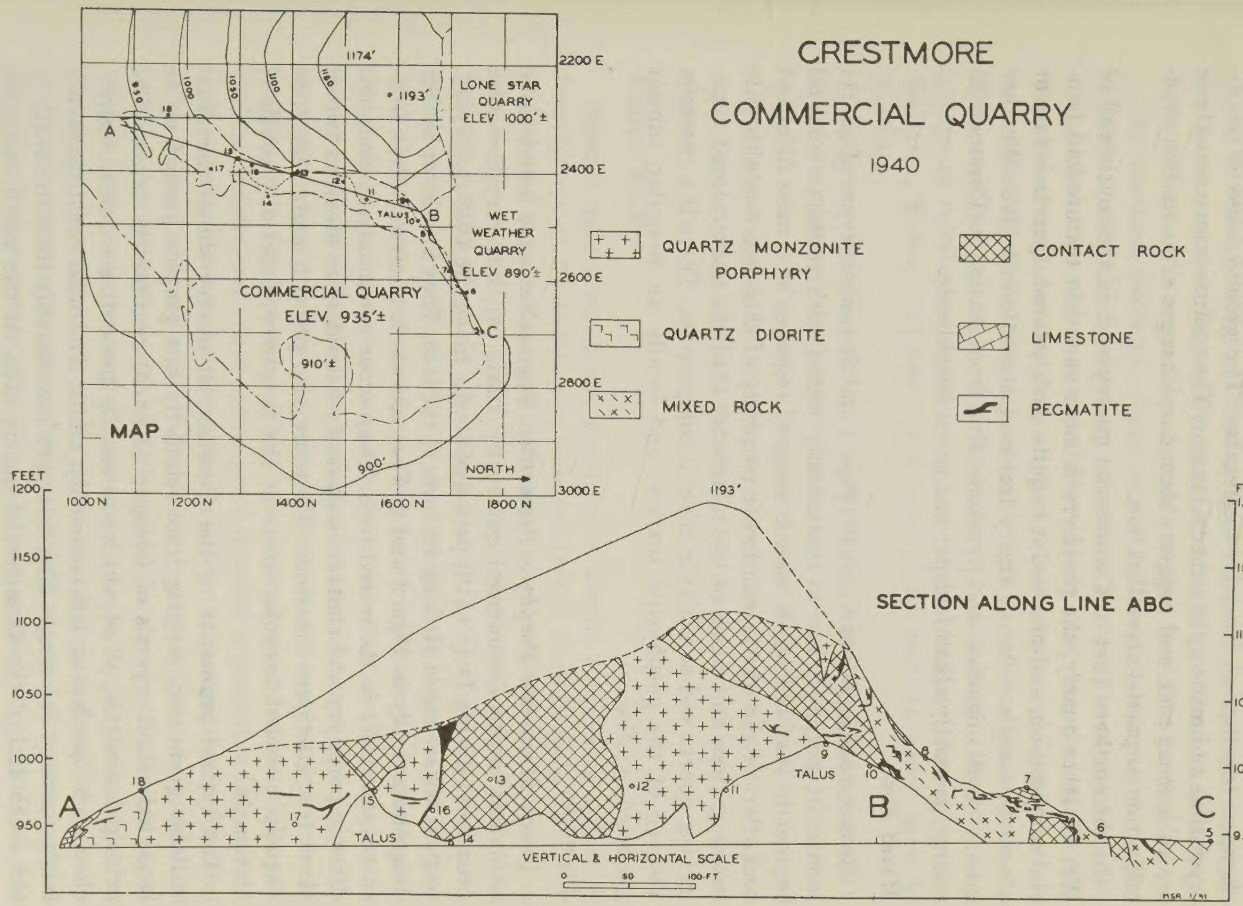

FIG. 3. Section across Commercial quarry, 1940. Index map ruled at 100-foot intervals.

anhedral and the pyroxene grains are both anhedral and commonly clumped together as irregular aggregates. The ground mass is microcrystalline and made up of anhedral grains. The texture is an unusual one for an igneous rock and suggests secondary changes after its first crystallization or partial crystallization.

In the northern part of Commercial quarry and on the south wall of Wet Weather quarry, the porphyry is more varied in texture and mineral composition, and much of it is quite dark colored. Quartz is rare or absent. A sample collected thirty feet east of station 31 (Wet Weather quarry) is all oligoclase and pyroxene. One from station 9 (Commercial quarry) is mostly alkali feldspar and green hornblende.

Mixed Rock

Between our locations 6 and 10 (Figs. 3 and 5) unusual types of quartz monzonite porphyry are so inextricably mixed with contact rock and pegmatite that the whole zone is mapped together as a mass of mixed rock. Part of the quartz monzonite porphyry of this area contains pale brown garnet, and much of the remainder is of the dark colored type, lacking quartz and of variable mineral composition. There is a common absence of the porphyritic texture, and locally an irregular, almost gneissoid banding.

Pegmatite

Quartz Monzonite Porphyry Pegmatites. Pegmatites were found to be abundant in the Commercial quarry by Eakle (4), but very few were prominent during Daly's (19) period of study. Since the 1938 quarrying, pegmatites are again striking features of the face. They are shown rather diagrammatically in Figs. 3 and 6. They are more numerous than indicated, especially in the mixed rock. They occur commonly as clean-cut dikes in porphyry and contact rock, rarely extending as much as two or three feet into pure limestone. They are also present, more rarely, as vaguely bounded irregular areas in the porphyry, especially south of station 16.

The typical pegmatite of the Commercial quarry shows the usual variable grain size, ranging from relatively fine graphic granite up to large individual crystals of feldspar 15 or 20 centimeters across. The principal minerals, all of which are usually present, are quartz, microcline, and oligoclase or, less commonly, albite. The other constituents are fairly constant in a single dike, but vary considerably from the north to the south end of the Commercial quarry face. At the north end, pale green epidote is present, and locally also axinite, treanorite, prehnite, datolite, zoisite (var. thulite), colorless garnet, zircon and several zeolites. At the south end, the rather large vertical dike near station 16 is characterized by 10% to 40% of andradite garnet in crystals one or two centimeters across. Treanorite, with a composition close to allanite, is fairly abundant in some dikes, notably in that containing andradite.

The northern dikes are characterized by cavities into which project crystals of microcline or epidote, or zeolites. Some of the cavities are partially filled with coarse anhedral blue calcite, just like that of the Sky Blue limestone, now obviously in the process of removal by solution. In such cases the calcite may represent the remains of blue limestone inclusions, especially as many inch-long bits and rarer larger masses of blue calcite, or calcite and wollastonite, are also present in the pegmatites. However, Kelley (22) has found blue calcite veinlets which must be secondary.

Much less common than the pegmatites are veins of pegmatitic aspect, which may lack either quartz or feldspar.

Quartz Diorite Pegmatites. Pegmatites are fully as abundant in and near the quartz diorite as they are in and near the porphyry. However, most such dikes are outside the small area with which this paper is concerned.

Contact Rocks

Normal quartz monzonite porphyry is almost everywhere separated from limestone by five to one hundred feet of contact rock. The most widespread type is composed primarily of grossularite garnet, with or without grass-green diopside. This rock is prominent on the summit of Sky Blue Hill and makes up a large part of the area of contact rock between stations 12 and 16 (Fig. 3). Near station 14 in the southeast part of the latter mass, and elsewhere, the garnet-rich material grades rapidly but irregularly into a rock composed in whole or in part of pale green or brown idocrase. Monticellite accompanies idocrase, and also forms almost pure brown or gray granular masses near limestone, or occurs as gray spots in the limestone. Elsewhere, and especially in the vicinity of residual calcite, very pale yellow-green diopside is present in large cleavable masses or well-formed crystals up to 5 or 10 centimeters in diameter (21). Along the south wall of Lone Star quarry a thin, nearly vertical sheet of fine grained, spurrite-bearing rock is a prominent element of the narrow contact zone which separates the porphyry, on the south, from the nearly pure limestone to the north. Locally, as in Lone Star quarry or at the extreme southern limit of our Commercial quarry section (quartz diorite contact, Fig. 3), masses of coarsely crystalline or fine silky white wollastonite are striking but minor features of the limestone side of contact rock. Numerous other mineral combinations are present and are discussed in more detail in connection with the profiles or the individual minerals.

At many places in the quartz monzonite porphyry contact rock and in the mixed rock, there are dark gray lenses of more or less decomposed biotite schist or gneiss, rarely more than five feet thick or fifteen feet long. Below station 7 a relatively fresh example is an oligoclase-biotite-hornblende-diopside rock, with perhaps 50% oligoclase. This biotite is brown in section, the hornblende green. The mica schist is perhaps the most puzzling part of the contact rock.

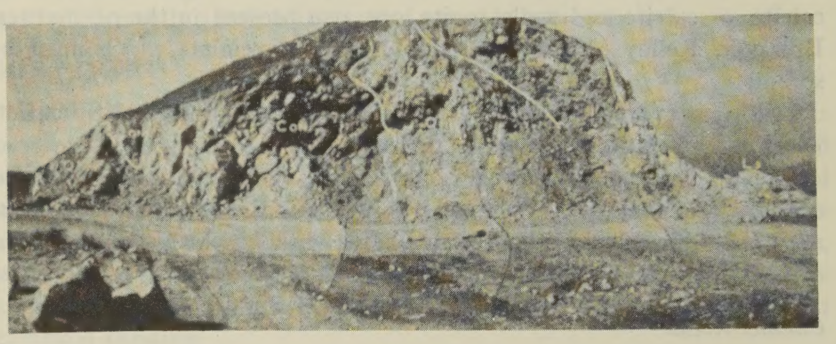

FIG. 4. Composite photograph of Commercial quarry face, February, 1940. QMP, quartz monzonite porphyry; Ls, limestone; Con, contact rock.

COMMERCIAL QUARRY PROFILE

As shown in Fig. 4, Commercial quarry is a bench cut deeply into the east side of Sky Blue Hill. Its floor is about 935 feet above sea level. The photograph (Fig. 4) and profile (Fig. 3) show the face on the west and northwest sides of this quarry as it was in late 1939 and early 1940. These figures also show approximately the condition which prevailed from 1916 to 1938, during the period of almost complete inactivity in Commercial quarry. In the autumn of 1938 much talus material was removed and the lower part of the face was cut back 10 to 50 feet between stations 11 and 14, without making great changes in the types of rock exposed. In 1939 a trench-like cut about 25 feet deep was excavated in the floor, extending west and south about 200 feet from the east edge of the quarry, almost entirely in limestone of varying degrees of purity. We are calling this new excavation the 910-foot level of the Commercial quarry.

Our Commercial quarry profile (Fig. 3) does not show the 910-foot level, but does begin just to the north of it where banded limestone and other rocks are exposed in the slope which extends down from the edge of Commercial quarry to the deeper Wet Weather quarry. The banding, especially where due to brucite nodules in calcite, is considered to represent original bedding, even though other types of banding, especially on the 910-foot level, are in planes almost at right angles to each other and may be due to replacement along joints. The brucite banding roughly parallels the boundaries of the limestone lens, where these are known.

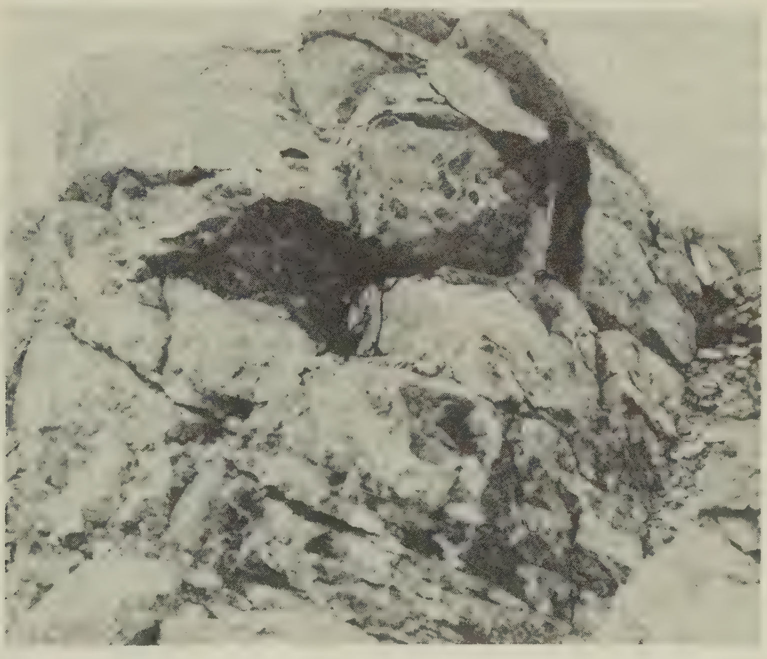

Fig. 5. Mixed rock beneath limestone of station 7, Commercial quarry, November, 1940. Man's hand points to one of several angular blocks of garnet rock, darker than the enveloping endomorphic monzonite porphyry. Lower right, larger mass of garnet rock, shown as such in Fig. 3. Lightest bands and veinlets mostly pegmatite. Left center, dark lens of biotite schist.

The banded limestone of stations 5 and 7 is underlain by a complex of contact rock, pegmatite and abnormal monzonite porphyry. Some details of this mixed rock are shown in Fig. 5. Others will be described in connection with a more detailed profile of the Wet Weather quarry wall. At and near the edge of the normal quartz monzonite porphyry, south of station 9, there is a somewhat similar migmatite. Numerous inclusions of garnet rock make a vaguely bounded band in the porphyry 10 to 15 feet from the contact at 9.

The following notes concern the main part of the face (*AB* on map and profile), and supplement the descriptions under the headings "Crestmore Rocks" and "Notes on Individual Minerals."

The pegmatite shown near station 10 is notable for its large epidote crystals projecting into cavities. Apparently this is the "coarse grained" rock mentioned by Kelley (22). The pegmatites near the top of the cliff above station 9 contained thin but extensive vugs lined with stout prismatic microcline crystals up to 15 cm. across. Microcline crystals of similar size and habit, showing Carlsbad twinning, were present in the pegmatites of the mixed rock below station 7, but there they were enclosed in clear massive quartz. The pegmatites between 7 and 9 have been the sources of specimens showing (1) thin blades of purple axinite, (2) pink thulite with oligoclase and microcline, (3) pale green datolite and green and pinkish prehnite, (4) zeolites both massive and in druses, and (5) fine clear apophyllite in cavities,—all in addition to the epidote mentioned above and a number of other minerals, as indicated elsewhere in this paper.

At the southern edge of the largest mass of garnet contact rock, near station 14, there are large masses of pale green idocrase which are called "californite" by collectors. Formerly, east of the present face, pale green pyramidal crystals of idocrase, one or two centimeters across, were thickly distributed through brownish contact rock composed chiefly of monticellite and custerite. Similar material now falls from the cliff above station 9.

Station 15 marks the bottom of a V-shaped downward extension of the summit garnet rock. The blue calcite veins in the garnet contain numerous long prisms of scapolite. Secondary radial phillipsite and a little translucent stilbite are also found here, and opalization is extensive.

The two principal surfaces of quartz monzonite porphyry which are exposed in the face, one between stations 9 and 12, the other between 16 and 18, are strikingly jointed. The most prominent joint system, approximately N 20°W 45°NE, is nearly but not exactly parallel to the contact with garnet rock above station 9 and also with the banding in the limestone at 5. Other prominent joints in the porphyry are nearly flat, perhaps with a NE dip of 0°–5°. At station 15 a prominent fault (?) running N 50°E 70°SE, extends into contact rock.

At "*A*", which marks the south end of the quarry face, the contact zone between limestone and quartz diorite is mostly garnet and wollastonite, and only a few feet thick, thus emphasizing the exceptional nature of the thick contact zones usually present alongside the quartz monzonite porphyry.

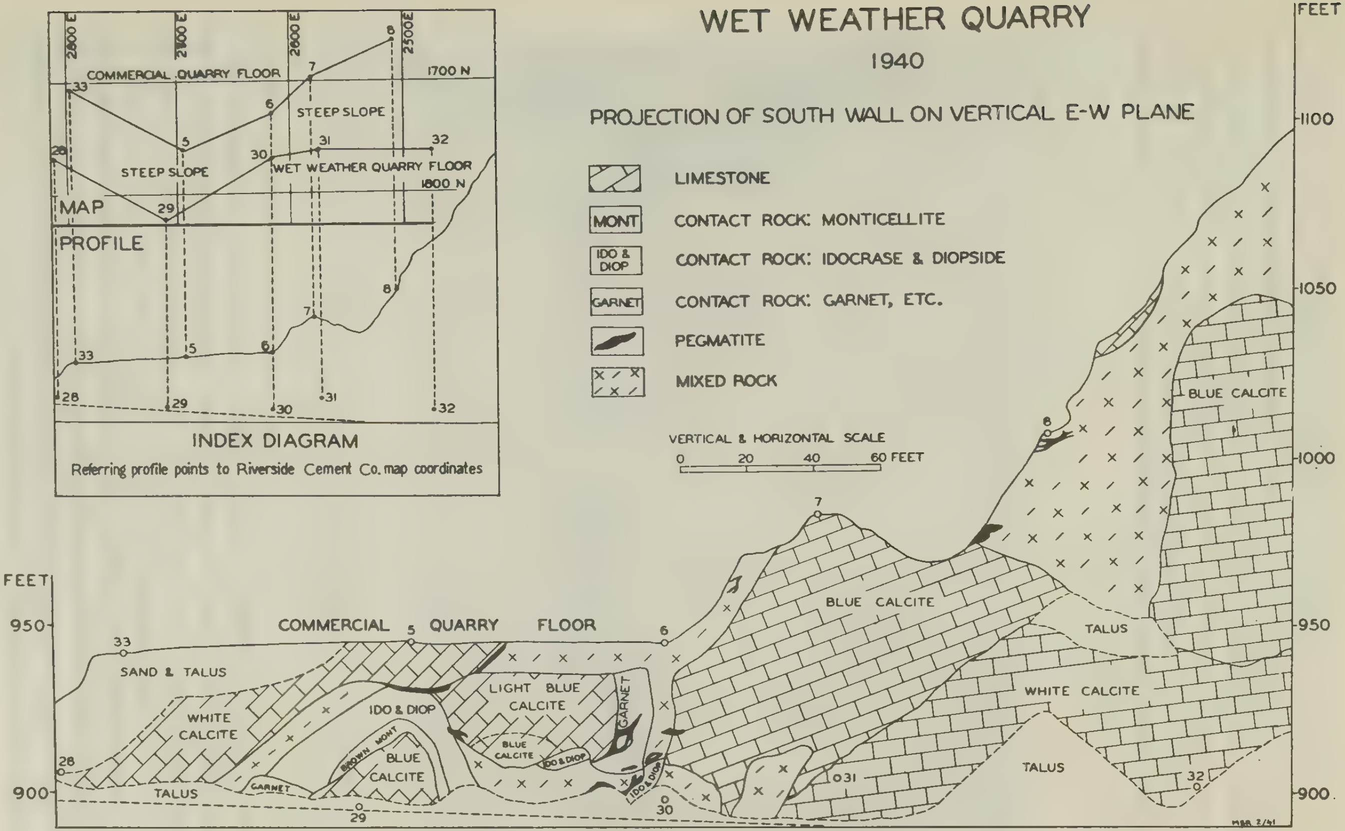

FIG. 6. South wall of Wet Weather quarry, 1940.

WET WEATHER QUARRY PROFILE

Exceptionally clear intrusive relationships, and the only example of the sharp segregation of the contact minerals into distinctive zones, are to be seen on the south wall of Wet Weather quarry, shown in Fig. 6. This section includes most of the *BC* portion of Fig. 3, seen in reverse. The central portion of the Wet Weather profile is shown in the photograph of the quarry, Fig. 7.

FIG. 7. South wall of Wet Weather quarry, September, 1940. Ls, limestone; Con, contact rock. Location numbers same as in Fig. 6.

At the left side of Fig. 6, the bedding in the limestone is indicated both by jointing and by brucite streaks 1 cm. thick and spaced at intervals of from 3 to 5 cms. The thickness of clearly bedded limestone is only 20 feet. The bedded limestone is underlain by a few feet of banded mixed rock. Underneath the banded rock is a complex of garnet rock cut by quartz monzonite porphyry stringers and succeeded by idocrase-diopside rock which apparently has developed down the dip of the bedded blue limestone below station 5, Commercial quarry.

Above station 29 a small mass of pure blue limestone is backed by and apparently almost surrounded by brown monticellite rock. A 4-inch layer of limestone adjacent to the monticellite is thickly studded with wollastonite and crestmoreite, cut by veinlets which may be altered thaumasite.

An idocrase-diopside zone follows the monticellite, between stations 29 and 30. This zone also contains monticellite, spurrite, and other minerals. It includes some quartz monzonite porphyry streaks, especially along its southwestern margin.

The limestone above 30 contains good crystals of idocrase and diopside, and rarely monticellite in prisms up to 8 cm. across, as well as large, 1 to 3 cm. pseudomorphs of crestmoreite after wilkeite.

Above station 30 pegmatite lenses and stringers are numerous. One lens in garnet rock is 12 18 inches thick and made up of medium to coarse grained microcline, oligoclase and andradite. It is shown very diagrammatically, partly because of dislocations due to blasting. A second lens cuts two feet into pure limestone; beyond its nose on the limestone cliff scattered crystals of green idocrase (?) seem to represent an extension of the pegmatitic influence. A nearby compound wollastonite-pegmatite veinlet between blue limestone and idocrase-diopside rock is composed of two layers. On the idocrase-diopside side there is fine-bladed wollastonite crystallized perpendicular to the walls. On the blue calcite side there are closely packed microcline crystals, without quartz, embedded in wollastonite and spotted with dark green pyroxene crystals. Some of the microcline crystals are shot through with wollastonite blades. The series of pegmatites along the limestone contact between stations 30 and 7 is one of the most persistent zones of this rock now exposed in the quarries. Many of the higher dikelets are not shown in Fig. 6.

West of location 30 the profile is simpler. Limestone remnants of the large mass excavated in the making of Wet Weather quarry remain still adhering to the silicate wall. Garnet-rich contact rock makes a layer only a very few feet thick between blue limestone and mixed rock which to the west becomes more and more predominantly a quartz monzonite porphyry. The most exceptional feature is the development of abundant black prisms of Mineral *B* (ludwigite?) in the vein-like margin of the limestone body at location 31.

Lone Star Quarry

Lone Star quarry has now (November, 1940) been excavated farther south than shown on the map of Fig. 3. There is now only a narrow ridge between Lone Star and Commercial quarries. The south wall of Lone Star presents a huge face of contact rock with blue calcite masses adhering to it in places, and quartz monzonite porphyry showing through where quarrying has removed both limestone and contact rock. The face is very steep (80°), rising over 100 feet above the Lone Star floor and at the east end continuing down to the floor of the Wet Weather Quarry 100 feet lower.

Quartz Diorite Contact Rock. At the west side of Lone Star quarry the enveloping quartz diorite is exposed, its contact with the overlying limestone lying N 52° E 45° SE. This contact also emerges 50 or 60 feet lower in the west wall of Wet Weather quarry. The limestone in contact with the quartz diorite is white with a fairly uniform development of red garnet and wollastonite contact rock about one foot thick. Epidote and quartz occur in small pegmatites projecting slightly into the calcite. Brucite is the commonest accessory mineral in the mass of the limestone, in bands roughly parallel to the quartz diorite contact. Chondrodite in dark green grains and 1 mm. crystals was found in very rare and limited occurrences near the contact; phlogopite in red-brown flakes and 5 mm. crystals rarely; magnetite as 1 mm. octahedrons in predazzite rarely; arsenopyrite, pyrite and pyrrhotite rare, near the contact; graphite rare; hydrotroilite rather abundant. The contact between the quartz monzonite porphyry and the quartz diorite cannot be seen here as yet.

Quartz Monzonite Porphyry Contact Rock. The layer of blue calcite and contact rock on the face of the quartz monzonite porphyry is here only 15 to 20 feet thick, and the change from blue to white limestone probably cuts across the banding (bedding?) of the brucite limestone, though we did not observe the progress of quarrying continuously and so cannot be entirely certain on this point. The principal contact minerals here are massive garnet, wollastonite, diopside, idocrase, monticellite and spurrite. Metamorphic zones near the quartz monzonite porphyry contact cannot be well ascertained, but the presence of large blocks of dark gray-green spurrite-bearing rock in the talus all along the face is notable. This rather fine-grained, massive rock also contains merwinite, gehlenite and monticellite, though not all are present in every sample. The largest block of spurrite rock found on the quarry floor was over four feet thick, least dimension, with veins and surfaces of silky, soft white thaumasite up to 5 cm. thick. Under the lens the thaumasite is seen to occur as closely grouped, radiating, acicular, hexagonal crystals with flat basal terminations.

Large blocks of pegmatite which have been blasted from the east end of the Lone Star face, are mostly very similar to those which have fallen into Commercial quarry from the opposite side of the same ridge. Exceptionally the pegmatitic masses contain blue calcite and wollastonite with cleavage surfaces 4 or 5 cms. across, and clear, colorless apophyllite with cleavage surfaces up to 15 mm. across.

TABLE 1. MINERALS OF CRESTMORE AND VICINITY

MINERALS		OCCURRENCE									REMARKS
Number		Station (in Comm. and Wet Weather quarries)	Quartz Diorite	Quartz Monzonite Porphyry	Quartz Monzonite Porphyry Pegmatite	Limestone, including Predazzite	Contact Rocks	Mixed Rock	Secondary Veins; Weathering Products	Miscellaneous and Uncertain	Legend: A: Accessory mineral C: Common F: Frequent G: of General distribution M: Constituent mineral R: Rare G>C>F>R WW: Wet Weather quarry Ch: Chino quarry LS: Lone Star quarry Mi: from the Mine 910...: 910 Ft. Level, Commercial quarry
1	Actinolite.......	7, 18							R		Felted layers on joints in contact rocks
2	Albite...........		M		M						
3	Allanite(?).......	18								R	Altered; cf. treanorite
4	Andradite Garnet.	16			C			F			Dark brown crystals of pegmatites
5	Andesine........										Vide Daly (19)
6	Anglesite........										Vide Eakle (4)
7	Apatite..........	14–16				R	R				
8	Apophyllite......	7 LS			R		R		R		Also silica pseudomorphs
9	Aragonite.......	LS 910							F		Rosettes
10	Arsenopyrite.....	12–14 Mi, WW				R					
11	Augite..........	15		M?			F	F			Vide Daly (19)
12	Axinite..........	8–10			R		R	R			Seams; thin purplish crystals
13	Azurite..........	Mi, etc.				R	R				
14	Biotite..........	18	M			M	M				Rock mineral
15	Bornite.........	Mi, etc.				R	R			R	
16	Brucite..........	Ch, LS, WW910				C					White or yellow grains
17	Bytownite-Anorthite.....			R						R	Vide Daly (19)
18	Calcite..........	G		F	F	M	M	F	F	F	
19	Centrallasite.....				R						Vide Foshag (11)
20	Cerussite........	10			R				R		Alteration of galena
21	Chalcedony......	9							R		
22	Chalcocite.......			R			R			R	
23	Chalcopyrite	14 WW					R				Crystals and masses in garnet-calcite contact rock
24	Chondrodite.....	WW				R					
25	Chrysocolla......	9							R		
26	Chrysotile.......	15					R				
27	Chlorite.........	29					R				
28	Clinochlore......	LS, etc.					R				
29	Clinozoisite......	12			R						Pale, striated, crystals
30	Crestmoreite.....	LS				C	C				Pseudomorphs after wilkeite
31	Cuprite.........	14					R				Alteration of chalcopyrite
32	Custerite........						R				
33	Danburite.......									R	M. Vonsen's collection, Petaluma, Calif.
34	Datolite.........	8			R						
35	Deweylite.......										Vide Daly (19)
36	Diallage.........				C						
37	Diopside........	G		M?		R	C	C			
38	Ellestadite.......	WW?					R				See McConnell (24)
39	Epidote.........	10, etc.			C.	R	F				Striated crystals; massive
40	Galena..........	10, etc.			R	R	F				
41	Gehlenite........	LS, WW, 4–5, 13–14					R				With spurrite; with plazolite (?)
42	Graphite........	WW, Ch				C					Abundant in Chino limestone

Table 1—*Continued*

Minerals		Occurrence									Remarks
Number		Station (in Comm. and Wet Weather quarries)	Quartz Diorite	Quartz Monzonite Porphyry	Quartz Monzonite Porphyry Pegmatite	Limestone, including Predazzite	Contact Rocks	Mixed Rock	Secondary Veins; Weathering Products	Miscellaneous and Uncertain	Legend: A: Accessory mineral C: Common F: Frequent G: of General distribution M: Constituent mineral R: Rare G>C>F>R WW: Wet Weather quarry Ch: Chino quarry LS: Lone Star quarry Mi: from the Mine 910...: 910 Ft. Level, Commercial quarry
43	Greenockite; Var.: Xanthochroite	9–10				R	R	R			Vide Eakle (4)
44	Grossularite Garnet	G				C	C	C			
45	Gypsum (Selenite)	LS							R		With sphalerite
46	Hornblende	15	M	R							
47	Hematite	LS, 13–15					R		R		Alteration of chalcopyrite, etc.
48	Hillebrandite; Var.: Foshagite	14-17, WW					R		R		Veins in idocrase
49	Hydromagnesite	WW, Ch				F			F		Alteration of brucite
50	Hydrotroilite	WW, LS				R					
51	Hypersthene										Vide Daly (19). Not at quarries
52	Idocrase	G				C	C	C			
53	Jurupaite	Com							R		Vide Eakle (9)
54	Kaolinite (?)	28							R		
55	Labradorite										Rock mineral (Eakle, 4; Daly, 19)
56	Laumontite	9–11			C						Abundant in pegmatites
57	Löllingite	Mi									Vide Kelley (22)
58	Limonite	WW, LS, 17							C		In contact rock, pseudomorphs after pyrite
59	Ludwigite (?)	WW, LS				R					=Mineral *B*
60	Magnesite (?)	910							R		Dense white veinlets; indices low, some water
61	Magnetite	WW, 10–11	A	A		R	R				1 mm. crystals in predazzite
62	Malachite	9–11							R		In garnet rock
63	Manganite (?)	14			R		R				
64	Merwinite	WW, 13					F				With spurrite; fine grained
65	Microcline	8–15			M						
66	Molybdenite	Mi						R		R	From mine, with garnet rock
67	Monticellite	8–14, WW, LS, 910				C	C				Usually brown or pink or glassy gray
68	Montmorillonite	Mi							R		With prehnite, from the mine
69	Muscovite									C	In schist and quartzite
70	Nontronite	15, etc.							C		
71	Okenite						R				Vide Eakle (4)
72	Oligoclase	8–15, etc.	M	M	M						
73	Opal (Common)	G							C		
	(Hyalite)	G							F		
74	Orthoclase	G	M	M							
75	Periclase					R					From mine, etc.
76	Phillipsite	15					R				
77	Phlogopite	7–8, Ch, LS					F				
78	Plazolite	14					R				Crystals; (?) massive, with gehlenite
79	Prehnite	8-9, etc.			C						
80	Pyrite		A	A	A		R				
81	Pyrrhotite	WW, Ch				R	C				Small crystals; large masses
82	Quartz	G	M	M	M		C				
83	Realgar	14					R				In brown monticellite
84	Riversideite	14					C				Veinlets in idocrase. ? =crestmoreite
85	Rutile	WW					R			R	
86	Scapolite	15, WW					R				White crystals in calcite veins in garnet; etc.
87	Sepiolite									R	Vide Daly (19)
88	Sericite								R	R	Especially in seams
89	Serpentine	910				R	R				

TABLE 1—*Continued*

MINERALS		OCCURRENCE									REMARKS
Number		Station (in Comm. and Wet Weather quarries)	Quartz Diorite	Quartz Monzonite Porphyry	Quartz Monzonite Porphyry Pegmatite	Limestone, including Predazzite	Contact Rocks	Mixed Rock	Secondary Veins; Weathering Products	Miscellaneous and Uncertain	Legend: A: Accessory mineral C: Common F: Frequent G: of General distribution M: Constituent mineral R: Rare G>C>F>R WW: Wet Weather quarry Ch: Chino quarry LS: Lone Star quarry Mi: from the Mine 910...: 910 Ft. Level, Commercial quarry
90	Sphalerite	WW, Ch			R		R	R			
91	Sphene	15, etc.	A	A	A			R			
92	Spinel	13–14, 910					R				Blue grains and crystals in pale green grossularite
93	Spurrite	29, LS, 4–5, 13–14					C				
94	Stibnite	WW					R				
95	Stilbite	15			R		R				With scapolite and phillipsite in calcite veins in garnet
96	Strontianite	LS									
97	Talc?	WW					R				With brown tourmaline
98	Tetrahedrite										Vide Eakle (4)
99	Thaumasite	LS, WW, 910, 16							C		Veins and joints in spurrite rock
100	Tilleyite						R				Vide Larsen and Dunham (16)
101	Tourmaline, Brown	WW					R				
102	Tourmaline; Var.: Schorl	10–18			R						More abundant in quartz diorite pegmatites
103	Treanorite	6–9, 17			C						Similar to allanite; fresh, glassy crystals
104	Uralite										Vide Daly (19)
105	Vermiculite	18	R						R		In quartz diorite pegmatites
106	Wilkeite	910, 8, 14, 29				F	R				Also from SE wall of Lone Star quarry
107	Wollastonite	G			F	F	C				Fine crystals; silky masses
108	Xanthophyllite	910, 13–16, WW				F	F				Usually in idocrase or calcite
109	Zircon	8–15	A	A	R						Dark brown crystals up to 5 mm. long
110	Zoisite; Var.: Thulite	8–10			R						Pink crystals up to 15 mm. long
	Mineral B	WW, LS				R					Fine crystals up to 15 mm. long. Ludwigite (?)
	Mineral C	LS							R		White, radiating, on altered wollastonite
	Mineral D	LS							R		White, radiating CaMg silicate in peg.-like vein cutting idocrase
	Mineral F	14, etc.							F		Blue films of CuCaAl Si-carbonate on joint cracks in garnet rock
	Mineral G	910					R				Brown pseudomorphs; MgAl silicate
	Mineral H	8–17			R						A high-index titanium-bearing tourmaline
	Mineral J	910					R				A white, silky radial CaAl silicate with Mineral *G*
	Mineral K	910							F		White, chalky prisms of CaAl Si-CO_3 on Mineral *P*
	Mineral L	15			R						White, soft ThCa silicate in andradite-feldspar-treanorite peg.
	Mineral M	15			R						An isotropic substance with Mineral *L*
	Mineral N	LS							C		Thin yellow films of PbCuCa vanadate on joint surfaces
	Mineral O	910							R		2–5 mm. yellow crystals resembling clinohumite, in blue calcite
	Mineral P	910							R		Colorless, triclinic crystals in seams in spurrite-calcite rock
	Mineral Q	WW							R		Soft white fibers on loose limestone blocks

NOTES ON INDIVIDUAL MINERALS

ACTINOLITE. Found somewhat sparingly near stations 7 and 18. At the former locality, the mineral occurs as coarsely fibrous, silky masses of pure actinolite, up to 8 cm. in length and 5 mm. in thickness. Chlorite green in color, it occurs in a coarse quartz-calcite-epidote vein of pegmatitic aspect. At the latter locality, actinolite in blade-like crystals averaging 5×30 mm. in size is found as a minor constituent of an altered pegmatite which cuts the quartz diorite and probably is genetically related to that rock.

ANDRADITE GARNET. Occurs abundantly near station 16 in a pegmatite composed of quartz, microcline, oligoclase, treanorite and chloritized pyroxene. The simple dodecadedral crystals found here measure up to 2 cm. in diameter, are semi-transparent, and hair brown in color. Spectrographic examination indicates a Ca Fe silicate, with Al subordinate to Fe, and Mg less than 1%. The refractive index, far above 1.74, and the specific gravity, 3.67 or a little higher, suggest an andradite containing 30%–40% of the grossularite molecule.

APATITE: Rare, between stations 14 and 16, as pale green, clouded, prismatic crystals 2–5 cm. in length, with rounded terminations. Mineral associates are coarsely crystalline blue calcite, idocrase, grossularite and diopside. Minute blue apatite crystals of the type mentioned by Eakle (4) now can be found only on the old Commercial quarry dump.

APOPHYLLITE. Fine, clear, fresh, short pyramidal crystals. Especially from Lone Star quarry, in cavities in limestone (or calcite pegmatite). Also, in Lone Star quarry and on the Commercial 910-foot level, completely altered to silica pseudomorphs which preserve the birefringence and interference figure of apophyllite. These pseudomorphs have been studied by E. H. Bailey.

ARAGONITE. Of rather general occurrence in crusts and veinlets, but found notably in two localities: (1) in the Lone Star quarry, as acicular crystals in gleaming stellate groups up to 15 mm. in diameter, lining small veinlets or cavities in limestone, (2) on the 910-foot level of the Commercial quarry, as similar rosettes of transparent crystals averaging 1×7 mm. in size, and showing *b*, *k* and *m* faces. Occurrences of the crust-like type of aragonite have been noted especially near stations 12 and 14 of the Commercial quarry.

BRUCITE. As alteration pseudomorphs of periclase, locally abundant in the limestone of Lone Star and Wet Weather quarries and the 910-foot level of Commercial quarry. Waxy, gray grains, 1–5 mm. in diameter. Much rarer here than in the Chino limestone.

CHLORITE. Found as thin, blue-green 1×1 mm. plates in blue calcite above station 29, Wet Weather quarry, with grossularite and wilkeite in blue limestone. Also very pale green clinochlore or prochlorite in Lone Star quarry, as groups of 5–10 mm. flakes forming the matrix of pale diopside crystals; biaxial, +, 2V $5° - 10°$, $\beta = \alpha = 1.582 \pm .002$, $\gamma - \alpha = .010 \pm$.

The most striking and exceptional chlorite is colorless and transparent, like isinglass, occurring sparingly as flexible plates 6 to 8 cm. across, associated with monticellite-idocrase rock near station 16. A slightly ferruginous Mg Al silicate; +, 2V practically 0°, $\alpha = \beta = 1.577 \pm .002$, $\gamma = 1.582 \pm .003$.

CLINOZOISITE. Found sparingly near station 12, in well-developed, pale brownish-green crystals, slightly striated parallel to elongation (*b*), and measuring up to 15 mm. in length. The crystals occurred as divergent groups in a feldspathic pegmatite cutting garnet rock. This clinozoisite is practically neutral with strong dispersion of the optic axes, and shows anomalous blue and yellow interference colors. Indices vary slightly about the following values: $\alpha = 1.713$, $\beta = 1.718$, $\gamma = 1.723$.

CRESTMOREITE. The soft, white, silky, hydrous calcium silicate minerals at Crestmore are not easily distinguished. Their optical properties are variable. Perhaps all should be called crestmoreite; perhaps riversideite (Eakle, 4) and even a third mineral should be recognized.

Cuprite (ferruginous): Found sparingly near station 14, both massive and as pseudomorphs of chalcopyrite measuring up to 1×2 cm. in size, in a garnet-calcite contact zone. Identification somewhat doubtful.

Diopside. See pyroxene.

Dolomite. Searched for, but not found at Crestmore.

Forsterite. Searched for, but not yet found at Crestmore, though it is present at Victoria quarry a few miles away.

Gehlenite. Rarely found near station 13, as grayish white to black, granular streaks, interleaved with plazolite (?) in braided veinlets averaging about 1 mm. in thickness; ω-1.659±.002, some grains anomalously biaxial with 2V about 5°. Also, in the Wet Weather quarry, below station 5, in spurrite-merwinite rock as colorless or pale yellow, smooth, $\frac{1}{2}$–1 mm. glassy grains in bluish limestone (Cf. Larsen & Foshag, ref. 10). It also occurs with euhedral idocrase and custerite (Tilley, ref. 14).

Grossularite Garnet. This common brown garnet is the most abundant contact mineral at Crestmore, as has been emphasized in previous papers. It frequently occurs in pure masses, some of which, when finely crystalline, have a sugary appearance, but when coarser, against calcite, may also show dodecahedral crystals up to several centimeters in diameter. Trapezohedral (*hll*) faces are rarer; they appear, for example, on a very pale green type, found with the yellow-brown form and with blue ceylonite near stations 13 and 14. Palest yellow, minute glassy garnets from a prehnite pegmatite near station 7 show dodecahedral and tetrahexahedral faces; they are slightly birefringent, with polysynthetic twinning and $n=1.76\pm$.

The various grossularites have not been specially studied, but indices have been determined ranging from 1.745±.003 to 1.780±.010.

The dark red-brown garnets associated with the dark green diopside in the quartz diorite contact zone on the west side of the Lone Star quarry appear from spectrographic data to be manganiferous grossularite-andradites. They develop many faced crystals against limestone, with large dodecahedral faces bordered by narrow hexoctahedral and trapezohedral faces. The paler grossularites in the quartz monzonite porphyry contact zone, a hundred feet southeast in the same quarry, are simple dodecahedrons.

Hillebrandite, var. Foshagite. Chalky white, fibrous, relatively brittle. Found as (1) irregular masses up to 1 cm. or more across, in idocrase rock near station 14; (2) near station 17 in veins 1 cm. thick and 10 cm. or more in length, intimately mingled with finely divided calcite in minor fault cracks, and closely resembling fine grained amphibole asbestos; (3) the original type material of Eakle (ref. 12), which has again been found in the Wet Weather quarry as cross-fiber masses 8–10 cm. in length, cutting greenish idocrase-rich rock. Some of the second type is so fine-grained that the indices of refraction and birefringence are intermediate between those of calcite and foshagite.

Laumontite. Probably the commonest zeolite at Crestmore. Found in pegmatite dikes and pegmatite-like calcite-bearing masses, such as occur near stations 9 and 11, where it is seen as white, friable masses (variety caporcianite), or interlacing crystals varying greatly in size. Also in more compact masses of radiating or parallel columnar units 3 to 8 mm. in length, and as 5 mm. crystals in cavities, showing the forms {110} and {001}. Optically variable; γ ranges from 1.515 to 1.526. In one case great dispersion $r>v$. The caporcianite variety has $\gamma=1.515$–1.517 and extinction of 40°–42° on cleavage pieces.

Monticellite. Monticellite was reported "of limited development and soon exhausted" by Eakle in 1917; and Daly listed it as rare in 1935. One type was described in detail by Moehlman and Gonyer (18). Our investigations have revealed monticellite in a wide range of color, abundantly present, in all the quarries except the Chino limestone quarries on the west side of Sky Blue Hill. It is commonly associated with blue calcite and with all the contact rocks owing their origin to the quartz monzonite porphyry intrusion, except wollastonite and garnet rocks. Even with these latter minerals, direct association has been observed by Moehlman and Gonyer (18). Monticellite occurs most abundantly between idocrase-diopside rock and blue calcite, frequently extending into each.

The commonest variety is massive and granular, usually pale to dark brown in color, more rarely practically colorless. The largest mass is present in Wet Weather quarry near station 29 (Fig. 6). Also at station 14, Commercial quarry; and at station 13—pale gray, with pink wilkeite and white crestmoreite. Blocks from the ridge northwest of station 8 show this variety, with custerite, forming the matrix of pale idocrase crystals (cf. Tilley, 1928). In Lone Star quarry it occurred in large quantity as nodular masses from 2 inches to 18 inches in diameter, which look like boulders or concretions. None were found in matrix. Some of these nodules, when broken, are found to contain inclusions of green idocrase; others change from brown to gray and colorless monticellite within, and contain blue calcite with crestmoreite in the center. The crestmoreite is often seen in the monticellite also.

The brown variety of monticellite occasionally forms prismatic crystals extending into the blue calcite, fine ones having been found at the Wet Weather and Commercial locations mentioned above. One 15×17 mm. crystal from station 14 shows {110} and {111} forms.

At station 14, Commercial quarry, pale yellowish and colorless monticellite occurs with spurrite and gehlenite. Also a rarer distinctly yellow form fills spaces in idocrase, associated with foshagite.

On the new 910-foot level of Commercial quarry, gray, vitreous, 10 to 20 mm. grains and crystals of monticellite occur in bands in the spurrite-calcite rock near yellow wilkeite. The brown variety also occurred here with blue calcite and green xanthophyllite crystals.

Monticellite (the Mineral "*A*" of Larsen and Foshag, ref. 10) is also a constituent, with merwinite, etc., of the rather fine-grained gray-green spurrite rock, which is so abundant along the southeast margin of the limestone in Lone Star quarry. Great blocks of this rock have fallen into Wet Weather quarry, and it may also have occurred in place there.

Optically the various color varieties of monticellite are similar, with $\beta = 1.645$–1.653, $\gamma - \alpha = .014 \pm .003$, sign negative with $2V = 80°$–$85°$. $G = 3.06$–3.11. The mineral is soluble in hot concentrated HCl, and yields appreciable amounts of Fe and Al, in addition to the predominant Ca, Mg, and Si.

MONTMORILLONITE. Soft, white and waxy clay-like material associated with calcite and granular prehnite in a four-inch vein along a N 30° E drift on the 700-foot level of the mine beneath the Chino quarry.

OPAL. (1) Colorless hyalite, more abundant than was indicated by Eakle (4). Commonly found as a coating on joint-planes, especially in garnet rock near station 12. (2) Brownish to black, banded "wood-opal", found in quantity near station 18, as the replacement of travertine, altered garnet, monticellite and fault-gouge materials.

PHILLIPSITE. Found very rarely on joint surfaces as lustrous silky-white, spherical or divergent, radiate groups of crystals 15–20 mm. in length: (1) near station 15 on contact rock composed of scapolite, blue calcite and cinnamon garnet, (2) on blue limestone of the 910-foot level. $\gamma - \alpha = .005$; indices close to 1.500. Fibers show $Z \wedge c$ 6°–10°. $H = 4.5$; $G = 2.16$; $F = 2$. Hydrous Al silicate, gelatinizing with HCl.

PHLOGOPITE. Occurs in relatively large flakes in limestone near station 30 and at station 29, both in Wet Weather quarry; also in the south end of the Chino quarry, and in the mine. At the first locality, greenish to reddish brown plates several centimeters across were found in a single specimen of white limestone; at 29, more numerous smaller green plates; at the third locality, small brown crystals 1 mm. or less in diameter, in limestone close to a contact with lavender, pyrrhotite-rich quartzite. From the Chino limestone of the mine, specimens of phlogopite measuring up to 4 cm. in diameter have been obtained.

In addition to the above localities, phlogopite has recently been found in the limestone of Lone Star and Wet Weather quarries, as colorless or pale green microscopic grains associated with idocrase and "Mineral *B*." $2V=0°$; $\beta=\gamma=1.583\pm.002$.

Plazolite (?). At station 14, white, fine-grained masses of a hydrous Ca Al silicate, containing some Mg and Fe, alternating in a braided structure with gehlenite. Somewhat opal-like in luster. Isotropic, $n=1.675\pm.005$. This material may or may not be the same substance as the minute, colorless or light yellow dodecahedral crystals described by Foshag (8). Probably the small amount of CO_2 shown by Foshag's analysis is not essential. In a letter dated August 2, 1940, Foshag states that the CO_2 may have come from included calcite. Pabst (23) ignored CO_2 in determining the crystal structure.

Prehnite. Found rather abundantly near stations 8 and 9 in semi-transparent green to white or brown crystalline masses, and in distinct, colorless 1×3 mm. crystals showing prominent {001}, {110}, and {101} faces; also common in crystalline aggregates which exhibit the usual "corrugated" surfaces. $\beta=1.627\pm.003$. In pegmatite, with oligoclase, quartz, datolite and treanorite.

Pyroxenes. Diopside is the principal pyroxene found in the contact rocks. The very pale variety described by Merriam and Laudermilk (21) and Eakle (4), with $\alpha=1.666$ and $\gamma=1.695$, has recently been found abundantly in Lone Star quarry. Good crystals up to 7 cm. long project into blue calcite. A grass green variety, +, $2V=55°–60°$, $\alpha=1.670\pm.003$, $\gamma=1.703\pm.003$, occurred in calcite east of the present face in Commercial quarry. The green pyroxene in the garnet rock usually has higher indices, e.g., $\alpha=1.688\pm.003$ for a specimen from the top of Sky Blue Hill above station 9.

Pyrrhotite. Fairly common in the Wet Weather quarry, in the Chino quarry and mine workings. In western Wet Weather quarry disseminated through limestone; also present above station 29 as lenticular masses 1 cm. or more across in a monticellite-idocrase rock. At the Chino quarry, it is found widespread granular or as crystals, especially distributed in small amounts throughout the quartzite. From the mine beneath, pyrrhotite masses weighing more than 500 pounds have been obtained occasionally, sometimes associated with "black-jack" sphalerite.

Riversideite. See crestmoreite discussion.

Scapolite. Good crystals of translucent to cloudy white scapolite, measuring 1 by 4 cm. and showing well-developed {110}, {100}, and {111} faces, occur near station 15, with blue calcite in garnet rock. $\omega=1.566\pm.001$ perhaps indicates dipyre. Also massive, in contact rock at station 13; ω variable, 1.553–1.576; H=5.5. Fine-grained scapolite has been found with brown tourmaline in a Wet Weather block of fine grained contact rock; its indices, $\omega=1.582\pm.002$, ϵ approximately 1.550, indicate mizzonite. Scapolite (dipyre?) was probably abundant locally in mixed rock and pegmatite, but is hard to identify because of alteration.

Sphene. Golden yellow, millimeter crystals of sphene are very abundant in some pegmatites. Larger brown crystals are also fairly common. A cavity in garnet rock, lined with brown sphene crystals, has been found in the southeast face of the Lone Star quarry by Mr. R. E. Campbell of Bloomington. The crystals are 5–10 mm. across, and show the common flat double wedge habit. Coarse, massive gray calcite has been partially dissolved from the cavity and much coarse massive albite remains. This sphene may be hydrothermal.

Spinel. The dark blue-green variety of spinel known as "ceylonite" has been found near station 14, where it occurs as translucent grains 1–4 mm. in length, with pale green grossularite garnet and granular calcite. The wilkeite-bearing limestone of the 910-foot level is locally peppered with smaller, very dark green, nearly black, spinel octahedrons.

Spurrite. (1) Pale bluish gray and snowy, to deep sky blue and clear. Rather abundant, in masses 1 to 10 cm. across. With calcite, idocrase, etc., above station 29 (Wet

Weather quarry), on the 910-foot level of Commercial quarry, with gehlenite near stations 13 and 14 in Commercial quarry, and in blocks from the top of the ridge above station 8. (2) In compact, pale to dark green, granular masses of widely varying sizes, near station 29. (3) Perhaps the most abundant constituent of the greenish gray spurrite-gehlenite-merwinite rock which makes up a considerable part of the contact rock above the southeast corner of the Lone Star quarry.

Stilbite. Very rare. In the pegmatite near station 15, in transparent, platy crystals up to 1 cm. in length, with the familiar divergent structure and characteristic, pearly luster. $\alpha=1.493\pm.002$, $\gamma=1.504\pm.003$.

Strontianite. Found in Lone Star quarry as white, tufted fibers in minute balls on a joint surface.

Talc?. Talc is doubtfully present as a minor constituent of a rock with brown tourmaline in Wet Weather quarry. Colorless flakes with hardness about 2; $2V=26°\pm4°$; $\alpha=1.548\pm.005$, $\beta=1.587\pm.002$, $\gamma=1.589\pm.002$.

Thaumasite. Abundant in Lone Star quarry and elsewhere in veinlets cutting spurrite rock as described by Foshag (7) and Larsen and Foshag (10). Also with calcite and crestmoreite forming the white silky matrix of some idocrase crystals from the Wet Weather quarry.

Tourmaline. Schorl has been found rather rarely in trigonal prisms up to 10 cm. in length in the quartz monzonite porphyry pegmatites, and thin, platy crystals 3 or 4 cm. long in seams. It is more abundant in the pegmatites associated with the quartz diorite.

Brown tourmaline prisms spotted a block of gray scapolite-bearing contact rock in Wet Weather quarry; ω = chocolate brown, $1.650\pm.002$; ϵ = pale greenish tan, $1.625\pm.005$.

Vermiculite. Near station 18, brown to black plates up to 15 mm. in diameter, probably derived by hydration from biotite. The mineral associations are pegmatitic in character, with schorl prominent.

Wilkeite. On the basis of information furnished by Mr. R. M. Wilke of Palo Alto, under date of November 29, 1940, we conclude that the original find of wilkeite, in blue calcite with idocrase, was made in the north central part of Commercial quarry, slightly north of east of the summit of Sky Blue Hill, near 1650N 2700E, Riverside Cement Co. coordinates. The mineral is now very rare in the main Commercial quarry. A few rose-colored grains with crestmoreite rims were found with monticellite at station 13. It still occurs in limited amount in the Wet Weather quarry above station 29, in typical pale rose-colored grains up to 3 mm. across, associated with crestmoreite. Uniaxial, neg., $\omega=1.651\pm.001$; $\omega-\epsilon$ approx. .009 at station 13, .005 at station 29. In November, 1940, pink hexagonal crystals 5–10 mm. wide were found alongside giant wollastonite crystals in blue calcite, a few centimeters from idocrase contact rock, in great blocks which fell into Wet Weather quarry from the ridge southwest of Lone Star quarry. These crystals are uniaxial, negative, with $\omega=1.657\pm.001$, $\epsilon=1.648\pm.002$, and may be ellestadite (24). Still more recently numerous patches and veinlets of similar pink wilkeite have been found in Wet Weather blocks which fell from the steep wall just northwest of station 8 (Fig. 6).

A yellow variety (wilkeite?) occurs as numerous distorted crystals and wheat-shaped grains on the 910-foot level of the Commercial quarry, where it is associated with calcite, glassy gray monticellite, crestmoreite, idocrase, etc. The yellow variety is biaxial, with 2V commonly 38° ± 2°, as estimated from interference figures. It is tentatively called wilkeite rather than a related mineral, as it is a calcium phosphate-carbonate-silicate-sulphate, with low birefringence and $\gamma=1.647$ to 1.650.

Wollastonite. In addition to the numerous occurrences of the massive mineral (see under "Contact Rock" and the descriptions ot the sections) well-formed crystals have recently been found at two localities. Near station 14, 1×2 cm. crystals show the forms

{001}, {101} and {100}, the associated minerals being blue calcite and grossularite. Blocks with yard-broad surfaces covered by even better crystals have tumbled down from the ridge southeast of Lone Star quarry. These crystals have not been studied, but they apparently belong to Eakle's second type (4, p. 334).

XANTHOPHYLLITE. Colorless xanthophyllite occurs as one to three mm. flakes closely associated with the commoner green variety, at and near station 13.

ZOISITE, var. THULITE. Bright pink crystals in pegmatites high on the face above stations 8 and 10. Practically colorless under the microscope. Apparently pigmented by a little iron and still less manganese. Indices low: e.g. $\alpha = 1.688 \pm .003$, $\gamma = 1.698 \pm .003$. Positive; 2V variable, ranging upward from about 60°. Intergrowths with and perhaps gradations to gray clinozoisite; the intergrowths in microscopic bands which resemble polysynthetic twin laminae.

ZIRCON. 1–3 mm. gray to brown zircon crystals, associated with oligoclase and other minerals of the pegmatites, near stations 8, 9, and 15 (cf. Foshag, ref. 8).

NEW OR UNDETERMINED MINERALS

We have twenty-five or thirty minerals from Crestmore which we have not been able to identify definitely with previously described species. Those which are briefly described below are, with two or three exceptions, thought to be new varieties or even new minerals. Those lettered *B*, *K*, *L* and *P* are considered especially worthy of further study. Several of the undetermined species which are not mentioned further in this paper, are probably zeolites.

TREANORITE. The pegmatites of the Commercial quarry contain fairly numerous black or gray, fresh, vitreous tabular crystals, usually of orthorhombic but sometimes of monoclinic aspect. The chemical composition is variable, in some cases very close to that of allanite. The optical properties are unusual for allanite or other members of the epidote group, and the interfacial angles and unit cell[3] have not been reconciled with those of allanite or epidote. The name treanorite has been proposed for the crystals of this type which were first studied (27). This variable mineral is being investigated further.

MINERAL B. Slender, black orthorhombic prisms up to 20 mm. in length have been found in the Sky Blue limestone (e.g. at station 31, Wet Weather quarry) as well as at Victoria City quarry in Riverside. Chemical analysis of a very small sample by J. D. Laudermilk shows that this mineral is an aluminous iron-magnesium borate which may be closely related to ludwigite. It is strongly pleochroic: X = pale green, Y = slightly darker green, Z = dark brown. $\alpha = 1.791$, probably $\pm .002$; $\gamma - \alpha = .095 \pm .010$. Crystallographically it has prism angles which could be reconciled with those of ludwigite and in addition numerous sharp terminal forms never before reported on ludwigite. This mineral is being investigated further by Mr. Edgar H. Bailey.

MINERAL C. Small white radiating groups of fibers locally developed in an inch-thick sheet of calcite and wollastonite in Lone Star quarry contact rock. A hydrous calcium aluminum silicate with $\alpha = 1.545 \pm .002$, and $\gamma = 1.549 \pm .002$. The fibers show parallel extinction and positive elongation. This appears to be a new mineral and it may be possible to obtain sufficient material for chemical analysis and a more exact determination of the optical and other properties.

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[3] Kindly determined approximately by W. H. Dore of the University of California.

MINERAL D. A second white mineral occurring in radiated groups 5–10 mm. across, with wollastonite, in a pegmatitic vein in Lone Star quarry, is a hydrous calcium magnesium silicate with minor aluminum. Parallel extinction; + elongation. For the fresh material, $\alpha = 1.513$ and $\gamma = 1.532$. After a summer in the laboratory: $\alpha = 1.518 \pm .002$, $\gamma = 1.536 \pm .002$. As no zeolite has this composition or these properties, the mineral is considered new.

MINERAL F. A secondary mineral, occurring as definitely crystalline blue films coating joint planes of the quartz monzonite prophyry and contact rock near the southern end of Commercial quarry. It is a copper calcium aluminum silico-carbonate with low birefringence and indices close to 1.70. This mineral is rather certainly new but occurs in such small quantities that it may not be possible to obtain sufficient material for a chemical analysis.

MINERAL G. The yellow wilkeite and white crestmoreite now exposed on the 910-foot level of the Commercial quarry are in some places accompanied by centimeter-long brownish black pseudomorphs of a monoclinic mineral. Apparently identical pseudomorphs have also been found in Lone Star quarry. The principal mineral present appears to be a hydrous magnesium aluminum silicate containing some calcium and iron. Optical properties are similar to those of an impure, iron-stained clay mineral, with low birefringence and indices mostly between 1.535 and 1.545. In one case monticellite cores are present but the original monoclinic mineral is more likely to have been a diopside or chondrodite. The angles measured on one or two well-preserved pseudomorphs are fairly close to those published for chondrodite but do not fit diopside. Murdoch and Webb (25, p. 350) have reported somewhat similar pseudomorphs, with forms suggesting diopside.

MINERAL H (Titanium-rich tourmaline). Large, well-formed, black crystals in the pegmatites of Commercial quarry and also in the pegmatites at North Hill and Victoria City quarries in Riverside. Spectrographic analysis indicates a titanium-rich tourmaline. Indices high, well above 1.74.

MINERAL J. A white silky radial mineral associated with mineral *G* on the 910-foot level of Commercial quarry. $\alpha = 1.551$, $\gamma = 1.553$; extinction parallel, elongation postive. A hydrous calcium silicate with some aluminum present. Perhaps okenite.

MINERAL K. Associated with mineral *P* on joint surfaces of the contact rock on the 910-foot level, Commercial quarry. Glassy, stout, hexagonal prisms with good terminations, and good prismatic cleavages. Angle of 47° 23′ ± 30′ between basal pinacoid and hexagonal pyramid. Uniaxial, negative, $\omega = 1.494 \pm .002$, $\epsilon = 1.467 \pm .003$. Calcium aluminum silico-carbonate. Alters, after a few hours' or days' exposure, to snowy white pseudomorphs with lower indices and less double refraction, α finally becoming about 1.459 and γ 1.466. The change may be due to dehydration, as the product seems to be still a silico-carbonate.

MINERAL L. Minute, chalky, white, tetragonal crystals, showing pyramids and basal pinacoids, occurring in the andradite-treanorite pegmatites at the south end of the Commercial quarry. Altered to a fine-grained crystalline aggregate with indices slightly below 1.64. Impure calcium thorium silicate. Perhaps close to thorite, perhaps a new mineral.

MINERAL M. Isotropic yellow particles included in mineral *L*. Index $1.520 \pm .002$.

MINERAL N. Yellow-green films on joint planes of the rocks in Lone Star quarry and elsewhere, which prove to be lead copper calcium vanadate. The indices of refraction and the double refraction are both extremely high. This is either a new mineral or perhaps a mixture of known vanadates.

MINERAL O. Yellow equidimensional crystals 3 to 10 mm. across, spotting the white limestone of the 910-foot level of the Commercial quarry. Clear, glassy, and exceptionally pure. A Mg(Ca) fluosilicate. Biaxial, positive, $\alpha = 1.625$, $\beta = 1.636$, and $\gamma = 1.655$. Slightly soluble in HCl. This mineral may be a member of the humite group.

MINERAL P. A colorless Ca Al Mg fluosilicate occurring as crusts and crystals in cracks of the limestone of the 910-foot level of the Commercial quarry, associated with mineral *K*.

Mineral *P* occurs massive and also as druses of numerous small triclinic crystals with many smooth faces. The axial elements are not close to those of any triclinic mineral with similar composition. Biaxial, +, 2V 35°–40°. $\alpha = 1.613 \pm .003$, $\beta = 1.619 \pm .002$, $\gamma = 1.630 \pm .002$. One excellent cleavage nearly normal to optic axial plane. This mineral is being investigated further by Mr. Edgar H. Bailey.

MINERAL Q. Soft, white, silky fibers, in cavities in limestone blocks found in Wet Weather quarry. A calcium silicate. Isotropic, $n = 1.482$.

CRYSTALS OF CONTACT MINERALS

In the contact zone good crystal faces against calcite are shown by several minerals, especially wollastonite, diopside, idocrase, garnet, and mineral *B*. Diopside, phlogopite, idocrase, mineral *B* and Eakle's second type of wollastonite (4) are present as more or less perfect crystals isolated in calcite near silicate contact zones. More commonly diopside and garnet crystals project into calcite from masses of contact rock. Garnets are rarely, if ever, complete crystals. Idocrase also has formed perfect pyramidal crystals in a silicate matrix of monticellite and custerite. Perhaps the greatest range in crystal size is shown by idocrase pyramids, which are very abundant in the millimeter size and rarely reach diameters of 100 or even 200 millimeters.

Some details concerning crystal forms have been given in the notes on individual minerals.

ORDER OF CRYSTALLIZATION

The relative ages of the minerals in the contact zones and other rocks have been given special consideration by Dunham (17) and Daly (19). Several genetic sequences have been traced, on various types of evidence.

Pseudomorphs of brucite after periclase and crestmoreite after wilkeite are well known at Crestmore, and the products of the alteration are abundant. There are also several other cases, including laumontite after feldspar, and even garnet after idocrase. The pyramidal garnet pseudomorphs, from station 15, Commercial quarry, have the refractive index $1.747 \pm .005$, which suggests almost pure grossularite.

No doubt most or all of the minerals of the sharply bounded pegmatites crystallized after those of the limestone contact zones which they penetrate. The order of crystallization in the pegmatites seems obscure, except for the single case of laumontite after feldspar.

Perhaps the most striking vein mineral is the white thaumasite which occurs in seams and thicker sheets cutting spurrite-merwinite rock. Foshagite is usually in cross-fiber veins in idocrase-rich rock. Other vein minerals include aragonite and strontianite, both perhaps quite recent crystallizations. Minerals *C*, *D*, *K*, *P* and *Q* are also vein minerals, cutting contact rock.

The carbonate and sulphate ore minerals listed in Table 1 are commonly associated with sulphides and are obviously oxidation products.

Nontronite, vermiculite, montmorillonite, kaolinite (?) and opal are alteration products, in part at least due to weathering. Weathering has also produced manganese stains, not represented in Table 1 because their mineral identity was not determined. Minerals *F* and *N* are probably products of weathering.

Conclusions as to Origin

All students of contact metamorphic rocks are indebted to N. L. Bowen for his illuminating discussion of contact metamorphism in siliceous limestone and dolomite.[4] We take his paper as the starting point for the few suggestions we wish to make concerning the origin of the contact minerals at Crestmore. Bowen emphasizes the early disappearance of dolomite in contact metamorphism and lists the disappearance of the ten following minerals as characteristic of ten stages in the metamorphism of a somewhat siliceous dolomite:

1. Tremolite
2. Forsterite
3. Diopside
4. Periclase
5. Wollastonite
6. Monticellite
7. Akermanite
8. Spurrite
9. Merwinite
10. Larnite

There have been found at Crestmore the minerals listed from 3 to 9 inclusive. But though some of the minerals are present in abundance, zones characterized by them individually (or by their absence) are missing, except very locally. Such a local series of mineral zones has been shown in Fig. 6, but its significance is not obvious, because the silicate zones lie between limestone bodies. Southeast of Lone Star quarry monticellite, merwinite, spurrite, and gehlenite (not akermanite) are intimately intergrown in the same rock; apparently they formed contemporaneously. Finally, the calcite common in most of the contact zones contains none of the brucite after periclase which is so abundant in the limestone outside the contact zones.

The space relationships seem to indicate rather clearly a general metamorphism of the whole mass of the limestone to beds of pure crystalline limestone and beds of predazzite. Near plutonic contacts there is also the development of a garnet zone which can hardly be explained except on the assumption of the addition of silica and other elements from the magma. Locally in the vicinity of the quartz monzonite porphyry and its associated pegmatites, the garnet zone is very greatly enlarged, and is characterized by paler garnet than elsewhere, and by the presence of numerous additional silicate minerals.

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[4] Progressive metamorphism of siliceous limestone and dolomite: *Jour. Geol.*, **48**, 225–274 (1940).

The Bowen series is indirectly useful here. The presence of diopside, wollastonite, monticellite, gehlenite, spurrite, and merwinite, more or less closely associated in the additive zone, suggests the presence of circulating solutions and perhaps much lower temperatures than those minerals would indicate in dry thermal metamorphism. On the other hand, the Bowen series cannot be used for the silica-free limestone outside the contact zone, and the presence of brucite after periclase, without other members of the series, does not necessarily mean that the temperature represented by tremolite, forsterite, and diopside had been exceeded.

The real nature and mode of intrusion of the quartz monzonite porphyry are not clear to us. Its principal masses, beneath the center of Sky Blue Hill, are crowned with and irregularly penetrate garnet rock and other contact rocks, and were nearly surrounded by a collar of Sky Blue limestone, now mostly removed. No considerable faulting has been demonstrated. If the porphyry invaded a rigid block composed of limestone and fully consolidated quartz diorite, the relationships would perhaps be explained most easily on the basis of assimilation and replacement of part of the Sky Blue (and Chino) limestone. Possibly the porphyry and the associated pegmatites have merely taken the place of dissolved limestone, part of the substance of which has gone off as carbon dioxide. We have as yet ascertained neither the dimensions of the porphyry underground nor the variations in its chemical composition, and so are unable to test such a speculation quantitatively.

Acknowledgments

We are indebted to the Riverside Cement Company for our base map and many courtesies. We feel especially grateful to Garner A. Beckett, president of the company, Howard R. Starke, superintendent, and R. H. Wightman, engineer. Mr. Wightman opened his records to us, and has criticized the manuscript.

Mr. Edgar H. Bailey worked with us through the academic year 1939–1940, in field and laboratory. Though he did not participate in the preparation of the manuscript, he has criticized it, and is practically a joint author. All goniometric work was done by him, and also a small part of the optical determinations here reported.

We are indebted to several members of the Claremont Colleges research staff. Dr. T. G. Kennard made numerous spectrographic determinations. Mr. David Howell contributed the laboratory photography. Mr. J. D. Laudermilk made several chemical analyses, the results of which have been used, though the analyses themselves remain unpublished.

Much of the best material which we have used was collected by Mrs. R. A. Crippen. We have also been aided by the field observations and collections of R. E. Campbell of Bloomington, Dr. J. W. Eggleston of Riverside Junior College, Howard Small of Riverside, and Melvin Swinney and Richard Strehle of Pomona College.

NOTE: Because of Dr. A. O. Woodford's recent illness he was unable to read the proof of this article. The junior authors, together with Mr. Edgar H. Bailey, assume full responsibility for any typographical errors which may be present.

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APATITE CRYSTALS WITH COLORED CORES IN VICTORIAN GRANITIC ROCKS

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Abstract

Some of the small apatite crystals in granitic rocks occasionally contain colored cores showing pleochroism. Because of their minuteness and scarcity, they can only be studied by optical means. A small proportion of the colored cores show optical properties comparable with those of hornblende, biotite and chlorite. The larger number of the cores show pleochroic color changes in shades of blue and brown, but cannot be conclusively identified with any particular mineral species. They appear to represent finely dispersed, partially resorbed ferromagnesian mineral matter, and to have had a contamination mode of origin, because the majority are associated with Victorian granitic rocks that have assimilated considerable amounts of foreign material.

Introduction

Attempts to determine the nature of the material composing the colored cores in certain apatite crystals have not been wholly successful. Chemical tests have so far proved unsuccessful (3, p. 7), and optical investigations have indicated the nature of only a few of the colored cores. Thus, in the granite of Brittany, some colored cores are considered to be chloritic and others composed of biotite (4, p. 94). The color effects resembling pleochroism in these cores are regarded as due to the reflection and transmission of light by numerous small included particles, the ranges of pleochroism depending upon the size and arrangement of these particles. Similar pleochroic cores in apatite crystals from the Eskdale granite in England, are regarded, despite the different colors, as due to finely divided chloritic inclusions around which the apatite crystallized (6, p. 375).

In the Victorian occurrences a small number of the colored cores can be identified with certainty as consisting of hornblende, chlorite and biotite, but there exists a larger group (later referred to as group *a*) with cores characteristically pleochroic from blue to brown tints, whose nature cannot be conclusively determined. In view of their scarcity and minuteness, it has been found impracticable to apply chemical tests, and optical investigations with the polarization microscope were the only tests resorted to.

Colored cores similar to those found in apatite crystals have not been observed in other minerals occurring in granitic rocks, even though many thousands of crystals in heavy mineral assemblages have been examined.

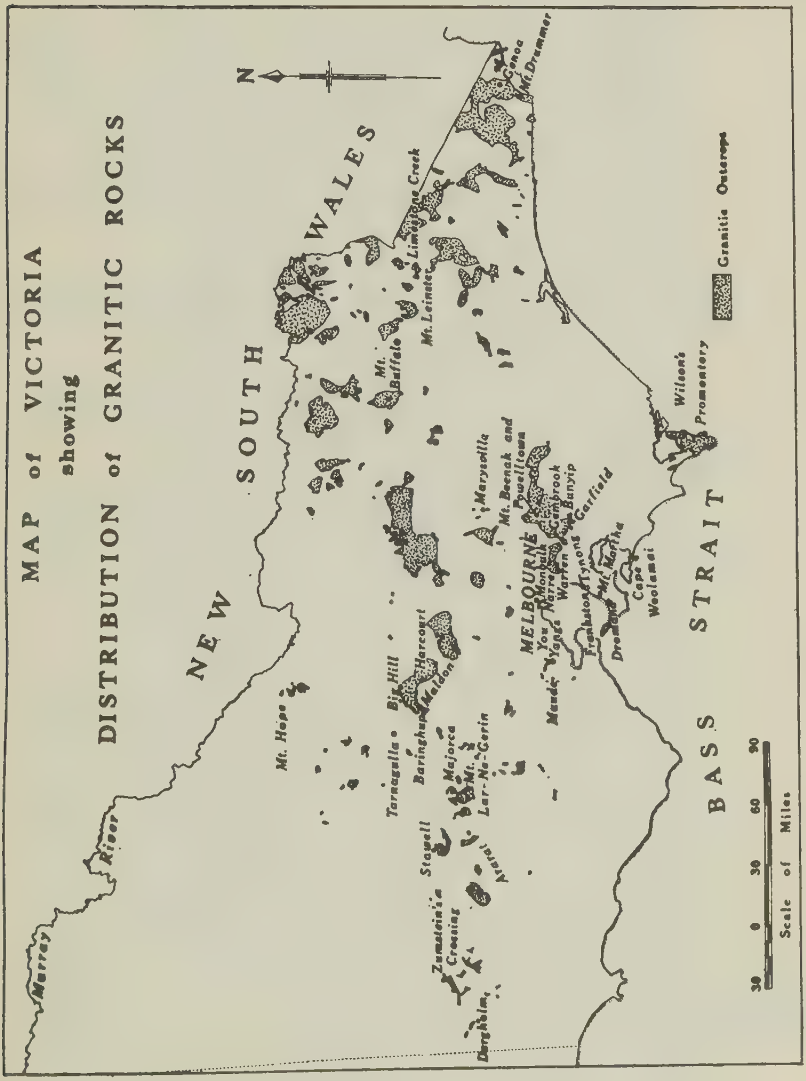

FIG. 1. Map of Victoria showing distribution of granitic rocks and localities mentioned in the text.

OCCURRENCES

Apatite crystals with colored, pleochroic cores were first noticed by the author in heavy mineral concentrates from the Dromana granite (1), but mention had been previously made of apatite crystals with carbonaceous cores in the granodiorite from Marysville (5). Examination of these crystals in the heavy mineral assemblages from the Marysville rock, shows that the cores display a color change as in other apatite crystals with pleochroic cores, and since no pleochroic effects have been observed for carbonaceous inclusions in minerals like chiastolite and andalusite, it is concluded that the material producing the coloration of the inner portions of these apatite crystals is not carbonaceous.

The study of over one hundred heavy mineral assemblages of Victorian granitic rocks, has revealed the presence of apatite crystals with colored cores in thirty-six of the assemblages, namely:

Granites—Cape Woolamai, Dromana, Mt. Buffalo, Dergholm, Mt. Lar-Ne-Gerin, Stawell, Bunyip, Mt. Hope, Powelltown, Mt. Beenak, Wilson's Promontory, Maude, You Yangs, Tynong, Garfield, Genoa and Gembrook.

Adamellite—Marysville.

Granodiorites—Maldon, Mt. Martha, Mt. Leinster, Harcourt, Zumstein's Crossing in the Grampians, Majorca, Oliver's Hill near Frankston, Limestone Creek, Mt. Eliza south of Frankston, Big Hill near Bendigo, Ararat, Narre Warren, Baringhup, Mt. Drummer, Tarnagulla, Powelltown, Marysville and Monbulk Creek in the Dandenongs.

The distribution of these occurrences is shown on the accompanying map (Fig 1.)

The apatite crystals with colored cores are not abundantly developed in these rocks. They are more frequent in varieties containing hornblende and also occur in hornblende diorite schlieren at Dromana (1). In individual heavy mineral assemblages they are most common from Dergholm, Tarnagulla and Big Hill, where some 30 to 40 crystals occur in each slide mount consisting of approximately 2,000 grains of the heavy minerals. In several of the granitic rocks, however, generally only one or two and seldom more than half a dozen crystals with colored cores are present in any one slide mount. In all of the heavy mineral assemblages, apatite crystals with colored cores are subordinate in amount to clear, colorless or pale yellowish-green apatites. None of the minute, needle-like crystals of apatite have been observed to contain colored cores.

NATURE AND PROPERTIES OF THE COLORED CORES

The length of the crystals with the colored cores varies from 0.05 mm. to 0.1 mm. in most examples. Larger ones in the granite from Mt. Lar-Ne-Gerin are up to 0.35 mm. in length. The coloring matter forming the cores may be brown, blue, purplish-blue, greenish, grayish or almost

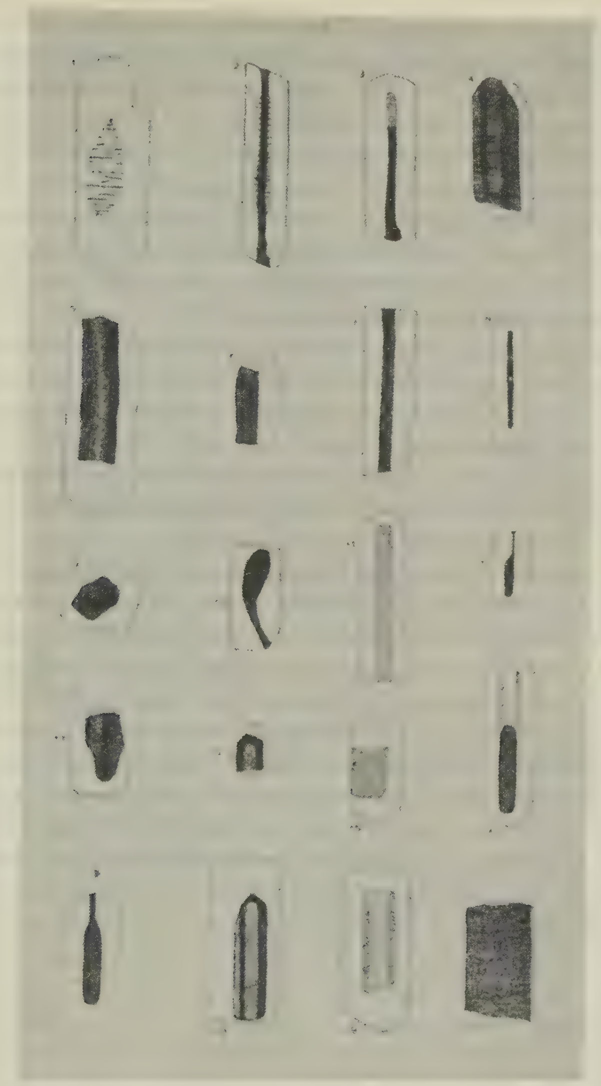

FIG. 2. The dots in the diagram do not indicate individual particles, but are shadings representing variations in density of coloration. Letters refer to the pleochroic group to which each crystal belongs, and figures (0.1 mm.), refer to the natural sizes.

Apatite crystals with colored cores from:

1. Powelltown granodiorite (*a*, 0.15 mm.).
2. Dergholm granite (*a* and *c*, 0.2 mm.).
3. Mt. Beenak granite (*c*, 0.1 mm.).
4. Zumstein's Crossing granite (*a*, 0.1 mm.).

black. At times this material is confined to the central portions of the crystals, and shows clear cut divisions from the colorless outer zones of apatite (Figs. 3, 7, 8, 11 and 19), but it may be evenly distributed throughout (Fig. 20), situated towards one side (Figs. 6 and 15) or one end, or somewhat irregular and bulbous (Figs. 10, 12 and 17). In some of the central cores a greater concentration of the coloring matter parallel to the long axis of the crystal has produced a marked banding effect, in which the darkest portions may be situated centrally (Fig. 7), laterally (Figs. 5 and 19), in a kind of zonal arrangement (Figs. 14 and 18), or in strips of alternating lighter and darker colors (Figs. 4 and 13).

Where apatite crystals with colored cores have fractured parallel to the basal pinacoid during the crushing treatment for heavy mineral separation, it is observed that some of the dark centers are more or less hexagonal in outline, and arranged parallel to the external form of the crystals (Fig. 9); similarly shaped occurrences noted from Irish granites are regarded as having been produced by the crystallization of colorless apatite around the dark central portions (8, p. 14).

In some crystals, the coloring material in the cores appears to consist of cloud-like suspensions of minute particles which vary in intensity of aggregation, and are almost sub-microscopic in size. In others, the material is so extremely fine as to be non-resolvable under the highest magnifications of the microscope, and an even coloration is then imparted to the central portions of the crystals, appearing merely as a faint stain, and only visible in some instances when the high power condenser is inserted. Sometimes the rather larger particles are arranged in a series of lines parallel to the short axis (Figs. 1, 2 and 20), and they appear to be confined to structural planes in the crystals. In one example, such lines of

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5. Tarnagulla granodiorite (*a*, 0.15 mm.).
6. Tarnagulla granodiorite (*a*, 0.1 mm.).
7. Mt. Hope granite (*a*, 0.125 mm.).
8. Stawell granite (*a*, 0.1 mm.).
9. Dergholm granite (*a*, 0.1 mm.).
10. Powelltown granite (*c*, 0.1 mm.).
11. Big Hill granodiorite (*a*, 0.2 mm.).
12. Mt. Martha granodiorite (*c*, 0.15 mm.).
13. Mt. Martha granodiorite (*a*, 0.1 mm.).
14. Big Hill granodiorite (*a*, 0.08 mm.).
15. Mt. Drummer granodiorite (*a*, 0.06 mm.).
16. Maldon granodiorite (*a* and *c*, 0.175 mm.).
17. Tynong granite (*c*, 0.06 mm.).
18. Limestone Creek granodiorite (*a*, 0.075 mm.).
19. Mt. Lar-Ne-Gerin granite (*a*, 0.1 mm.).
20. Genoa granite (*a*, 0.125 mm.).

denser aggregation traverse banded portions of the core (Fig. 4). The rounded darker parts in the central hexagonal core shown in Fig. 9 suggest that dark strips such as are indicated in Fig. 4, trending parallel to the long axis of the crystal, are cylindrical in habit.

The majority of the colored cores are pleochroic, some of them only weakly so, and a small number display no pleochroism whatsoever. The pleochroic changes are grouped thus: (*a*) from almost black, dark purple, paler purple, purplish-blue, blue, grayish-blue and gray to lighter or darker shades of brown, grayish-brown and purplish-brown; (*b*) from darker to lighter greenish-brown or from bluish-green to greenish-brown; and (*c*) from dark brown or black to lighter brown. The faint stain-like colorations in some of the cores of group (*a*) are only weakly pleochroic in contrast to examples from the hornblende diorite schlieren at Dromana (1), in which the whole of the strongly colored crystals are pleochroic from a deep azure-blue to brown. In rare examples from Maldon (Fig. 16) and Dergholm (Fig. 2), material of groups (*a*) and (*c*) are associated together in the same crystal.

The presence of the purple and blue to brown pleochoric matter of group (*a*) does not affect the birefringence of the apatite crystals. Cores of group (*b*) do, and the polarization colors which show above the low order colors of apatite, together with the value of the extinction angle, indicate that this type of included material is comparable with hornblende. Colored cores of group (*c*) are also birefringent; the polarization colors, the pleochroic colors and the positions of maximum absorption in plane polarized light, correspond to those of biotite. This determination was confirmed from a bleb of biotite which protrudes through the broken end of an apatite crystal in the Tynong granite (Fig. 17). Dark greenish colored, non-pleochroic cores are rare, one occurring at Mt. Martha (Fig. 12) and one at Baringhup. These are probably chloritic in nature, and in view of their rarity, have not been assigned to a special group.

In groups (*b*) and (*c*), the material composing the cores is lath-, bleb- or rod-like in shape, and can be correlated with definite mineral species like hornblende, biotite or chlorite. Such cores form a minority among the colored pleochoric apatites, the bulk of the cores occurring in group (*a*). Colored cores of groups (*b*) and (*c*) occur in the granitic rocks from the You Yangs, Garfield, Cape Woolamai, Powelltown (granite), Gembrook and Mt. Beenak. None of these rocks contain apatite crystals with cores of group (*a*), and in them the biotite group is of most frequent occurrence. In some rocks, apatites with cores of groups (*a*), (*c*) and sometimes (*b*) are all represented in the same heavy mineral assemblage, as at Oliver's Hill, Mt. Eliza, Monbulk Creek, Mt. Martha, Maldon, Baringhup, Marysville (granodiorite), Tynong, Dergholm, Bunyip, and Genoa. In the remaining nineteen granitic rocks from which pleochroic apatites are recorded, the colored cores belong exclusively to group (*a*).

The types of color changes in the cores of group (*a*) are comparable with those of certain varieties of tourmaline, but the positions of maximum absorption are similar to those for hornblende and biotite, agreeing with Smithson's determinations for occurrences in the Leinster (Ireland) granite, where the colors are darkest for the fast ray (9, p. 469). The fact that the directions of the color changes in this group of pleochroic cores are not comparable with those for tourmaline or for other colored pleochroic minerals of similar genesis, eliminates the possibility of the containing apatites having developed from processes of pneumatolysis.

The coloring material in the cores of group (*a*), is no doubt due to finely dispersed mineral particles. These obviously crystallized earlier than the apatite in the cooling history of the magma. It is to be expected that the first formed portions of the growing crystal of apatite would separate out slowly from the magma, as the earlier-formed mineral substance, acting as a nucleus to the crystallizing apatite, gradually became incorporated and partially resorbed. Further crystallization of the apatite in the clear rim was probably more rapid. The interior portions of the crystals would thus be unable to eliminate the impure residuum, which would remain confined to the inner portions, with a sharp line of demarcation between it and the clear outer rim. In some instances the coloring matter becomes relegated to structural planes in the internal portions of the crystals, and the density of coloration depends upon the degree to which resorption occurred. This process of formation conforms to the theory that the included particles were incorporated in later formed apatite crystals (6), rather than being products of simultaneous crystallization formed by rhythmic precipitation (4), where an inner zone of clear apatite would be expected within the colored cores as explained by Simpson (6, p. 377). No such crystals with clear inner zones have been observed in the Eskdale granites (6) or in Victorian occurrences.

The apatites with colored cores in granitic rocks differ from the dusky apatite crystals described from volcanic rocks at Kerguelen (2, p. 89) and from trachyte in the Macedon District, Victoria (7), in being more definitely colored and more pronouncedly pleochroic, less fibrous in appearance and less crowded with dark colored inclusions.

With respect to their position in the order of crystallization, only the cores of the group (*a*) type have been observed in association with the other minerals in the rocks. In thin sections of the Dromana and Marysville (granodiorite) rocks they occur as inclusions in biotite plates, and must therefore have crystallized prior to the main crop of biotite. Crystals with pleochroic cores assignable to biotite, however, indicate that small blebs and plates of biotite had formed before the appearance of the apatite, for which they acted as centers of crystallization. The apatites with colored cores also crystallized earlier than clear colorless apatites, as instanced by an occurrence from Mt. Leinster in Victoria, where a blue to brown pleochroic crystal is included in a larger colorless apatite (Fig 18).

The relationship between the blue to brown pleochroic material of group (*a*) and biotite cores of group (*c*) is provided by an occurrence from the Dergholm granite. In the same crystal, a central rod-like core of biotite is traversed by parallel lines of the blue to brown pleochroic material (Fig. 2) in such a manner as to suggest that the biotite portion of the core was the first to develop.

CONCLUSIONS

Pleochroic cores of groups (*b*) and (*c*) in apatite crystals present no difficulties of identification. The material forming cores of the group (*a*) type, cannot be identified with any particular mineral species with certainty, but the evidence available suggests that it is partially resorbed ferro-magnesian material. The degree of fineness of dispersal of residual particles is responsible for the differences in the pleochroic color effects occurring within this group.

The occurrence in the heavy residues of hornblende diorite schlieren from Dromana, of rare altered hornblende crystals containing purplish-blue to brownish pleochroic material along cleavage directions, comparable in color change with the pleochroic material in the cores of group (*a*) in apatite crystals, suggests that altered hornblende may be responsible for this type of pleochroic core in the apatite crystals of this rock. The altered hornblende would become included in the apatite crystals during the process of breaking down of the hornblende, the apatite probably being produced during a reaction involving the removal of lime from the hornblende, and the supply of P_2O_5 from the magma. The incorporated hornblende would thus become impoverished in lime, and the residual material would have a composition somewhat analogous to that of riebeckite, which shows pleochroic color changes comparable with those of the colored apatite cores of group (*a*).

The intimate association of apatite crystals having blue to brown pleochroic cores, with clots of ferro-magnesian minerals in contaminated portions of the Marysville granodiorite, may provide some indication of one of the sources of colored apatites. The clots, which consist of hornblende and biotite with associated sillimanite, are derived from incorporated sedimentary rocks (5), and although the crystals with colored cores are not observed within the xenoliths contained in this granodiorite, they have probably developed as a consequence of contamination by assimilation, as they are confined to those parts of the granodiorite in which evidence of xenolithic digestion is most pronounced. On the other hand, pleochroic apatite crystals at Maldon, are more common in biotite-rich xenoliths than in the granodiorite host rock. Crystals with similar pleochroic cores in the granite at Dromana were derived from the assimilation of hornblende diorite schlieren, and as these crystals were formed in the schlieren during the period of instability of the hornblende, when granitization was in progress, they would be xenocrystal when occurring in the granite.

Although apatite crystals with colored pleochroic cores are wanting in several Victorian granitic rocks which provide evidence of contamination by the assimilation of foreign rocks, and although a small number of examples occur in rocks showing little evidence of the effects of contamination, the general conclusion from the above investigations, is that as the majority of apatite crystals with pleochroic cores in Victoria are frequently closely associated with granitic rocks showing indisputable signs of having assimilated foreign rocks, and as most of the lesser contaminated granitic rocks are free from pleochroic apatites, such apatite crystals have a contamination mode of origin.

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LINEAR THERMAL EXPANSION OF ADULARIA

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ABSTRACT

Adularia from Grisons, Switzerland, was studied from 0° to 1000° C. parallel to the three crystallographic directions for linear thermal expansion and other thermal changes. The results indicate a large expansion parallel to *a*, a very small negative value parallel to *b*, and a very small positive value parallel to *c*. Abrupt changes in the rate of expansion or contraction occurred at twelve temperature regions, beginning at 120° and ending at 950°.

INTRODUCTORY

In planning the program of thermal expansion studies of the feldspars, it seemed best to begin with adularia because it most closely approaches the composition of pure potash feldspar. In subsequent investigations, it is proposed to work with other members of the alkali series, this to be followed by the plagioclase sequence.

All sections were cut from a single crystal of milky adularia from Val Cristallina, Grisons, Switzerland. The density is $d_{20}=2.559$ and the refractive indices are: $\alpha=1.519$, $\beta=1.523$, $\gamma=1.525$. From its chemical analysis,* given in Table 1, it may be computed that the crystal consists of 93.2 per cent potash feldspar and 6.3 per cent soda feldspar, all other constituents amounting to 0.5 per cent.

TABLE 1. ANALYSIS OF ADULARIA FROM GRISONS, SWITZERLAND

SiO_2	64.69
Al_2O_3	18.69
Fe_2O_3 FeO	0.04
MgO	0.07
CaO	0.03
Na_2O	0.74
K_2O	15.78
TiO_2	0.00
H_2O+	0.07
H_2O-	0.03
	100.14

Three sections, approximately 4×4×10 mm. were cut parallel to each crystallographic axis, all of them being almost clear and transparent. These sections were studied from 0° to 1000° C. by the method described in a previous paper.[1] After cooling from 1000° to room temperature every section displayed a marked pearly opalescence which was not visible in the unheated samples.

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* Analysis by Laboratory for Rock Analysis, University of Minnesota, Minneapolis.

[1] Rosenholtz, J. L., and Smith, D. T., Linear thermal expansion and inversions of quartz, var. rock crystal: *Am. Mineral.*, **26,** 103–109 (1941).

Experimental Results

The total expansions for the crystallographic orientations are shown in Fig. 1. All curves, if unobscured by the abrupt changes in rate of expansion, show changes in flexure which give them the shape of a flat, open S. The mean coefficients of linear thermal expansion for each crystallographic direction are given in Table 2.

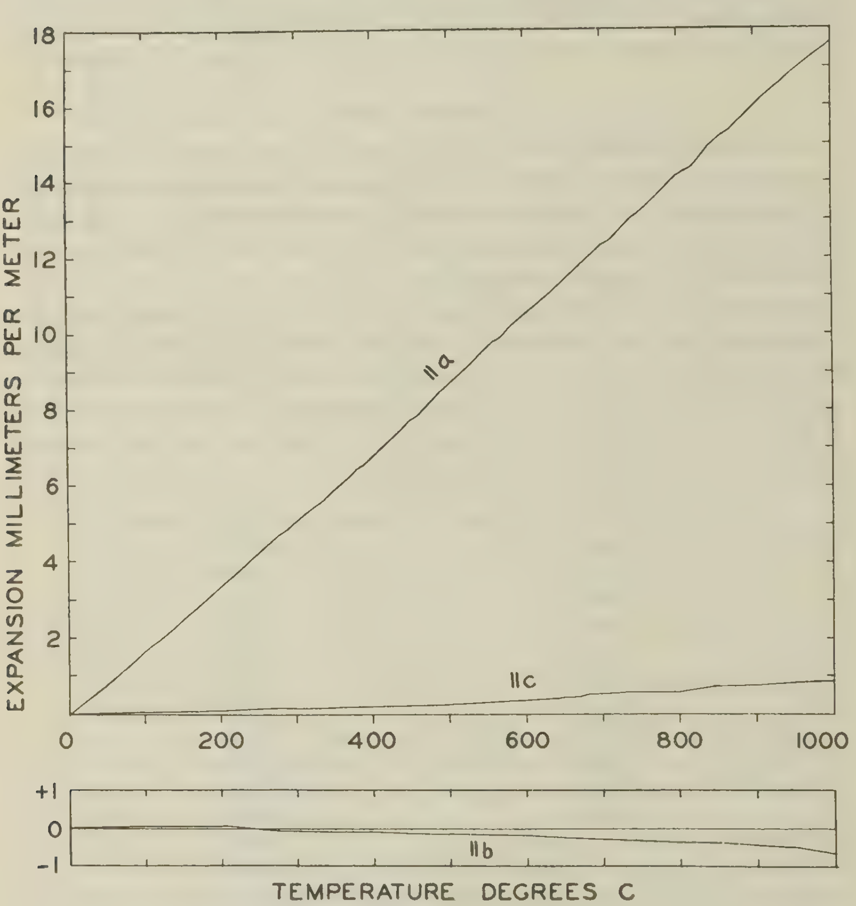

Fig. 1. Linear thermal expansion of adularia.

Kôzu and Saiki[2] have made somewhat similar studies on adularia from St. Gotthard, the composition of which is given as $Or_{83}Ab_9An_3$. For the direction parallel to *a*, there is a reasonably good agreement with the coefficients given above. Their results parallel to the *b* axis, obtained from only one section, are completely different from those in Table 2. For example, they report no change at 100° and positive values from 150° upward. At 1000°, they found a coefficient of $+1.40$ as compared with -0.65 reported in this investigation. It is impossible to compare the *c* directions because their third sections were in the direction of the perpendicular to the base, rather than being parallel to the *c*-axis. It is of interest to observe, however, that they report values of 2.65 and 3.65 at 1000° on two such samples.

TABLE 2. MEAN COEFFICIENTS OF LINEAR THERMAL EXPANSION FOR ADULARIA

0° C. to	Parallel to *a* $10^6\,\delta_m$	Parallel to *b* $10^6\,\delta_m$	Parallel to *c* $10^6\,\delta_m$
100°	16.40	+0.49	0.49
200°	16.63	+0.27	0.46
300°	16.78	−0.30	0.44
400°	16.88	−0.24	0.50
500°	17.30	−0.30	0.51
600°	17.51	−0.31	0.60
700°	17.58	−0.38	0.78
800°	17.68	−0.43	0.86
900°	17.73	−0.47	0.88
1000°	17.62	−0.65	0.86

Several special sections were cut at various angles between *b* and *c* axial directions. Expansion studies of these sections showed the same mean coefficient of 0.49 at 100°, with intermediate values between $\delta_{m\|b}$ and $\delta_{m\|c}$ at higher temperatures. It is possible to obtain directional sections in which δ_m to 1000° is zero, although at lower temperatures a very small positive coefficient is obtained.

Abrupt changes in the rate of expansion or contraction were observed during the heating of all sections. Since none of these changes are large, it was necessary to make observations at intervals of not more than 10° throughout. The rate changes were observed at 120°, 260°, 285°, 400°, 475°, 560°, 680°, 740°, 820°, 855°, 900° and 950°. The temperature variation in each region is ±5°. Kôzu and Saiki (*loc. cit.*) reported five temperatures for changes in the expansion rate and two additional temperatures where change in the optic angle was observed. For the purpose of comparison, these are given in Table 3, together with the temperatures listed above.

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[2] Kôzu, S., and Saiki, S., *Sci. Rep. Tôhoku Imp. Univ.*, Ser. **III**, 2, 203–238 (1925).

Some sections showed a permanent change in length after cooling to room temperature. For the *a* direction, one showed no change, the second was 0.04 per cent longer, and the third 0.13 per cent longer. For the *b* direction, one showed no change but the other two were shorter by 0.04 and 0.05 per cent, respectively. Of the three *c* sections, only one showed a change, it being an elongation of 0.07 per cent.

TABLE 3. TEMPERATURES OF CHANGES IN ADULARIA

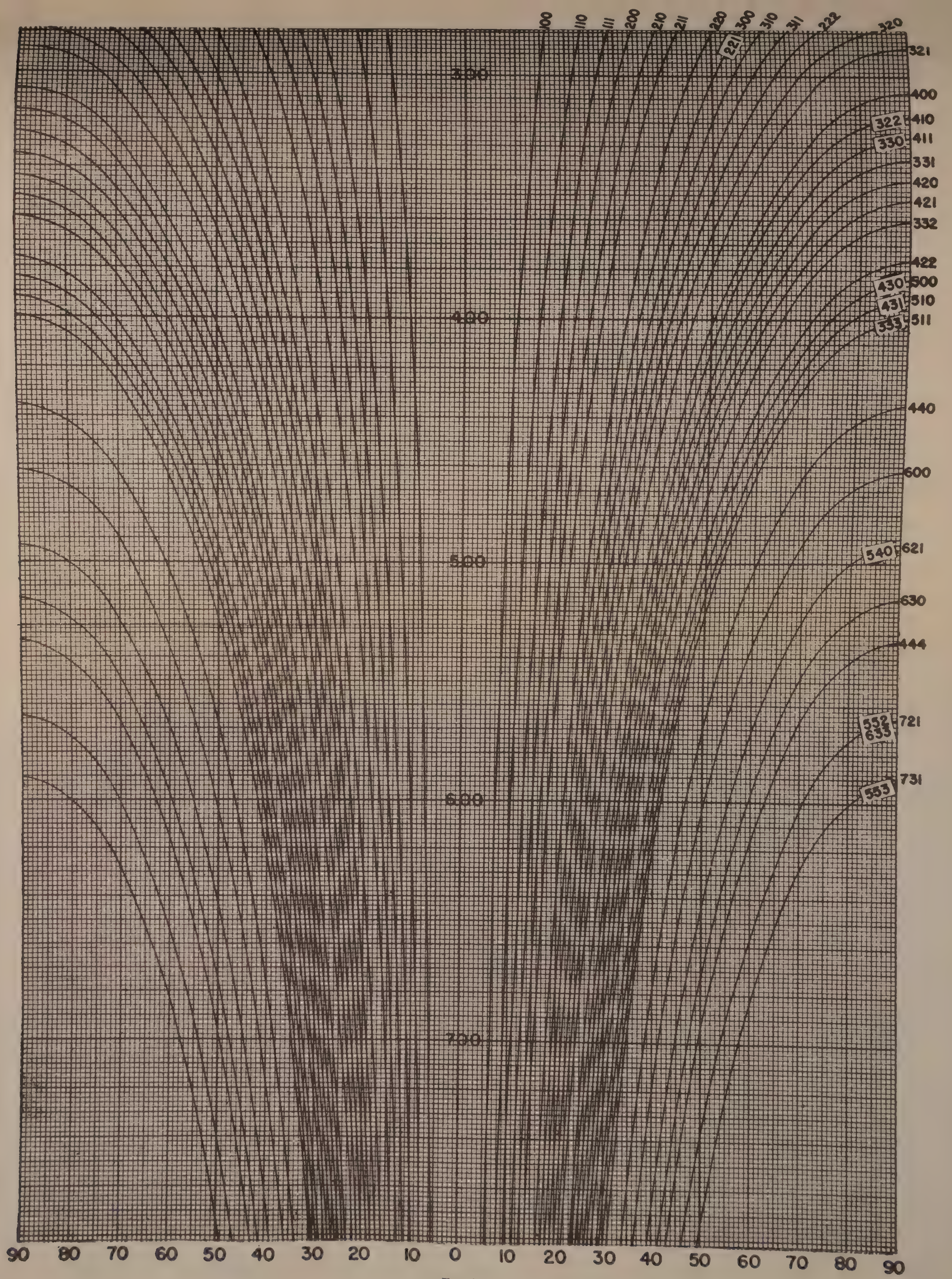
R. & S.	Kôzu and Saiki
120°	
260°	270°—Expansion change
285°	
400°	
475°	475°—Expansion change
560°	
680°	675°—Expansion change
	700°—Optic angle change
740°	
820°	
855°	850° to 900°—Optic angle change
900°	900°—Expansion change
950°	950°—Expansion change

The analysis of the above data presents a most intriguing problem. The 900° change may perhaps be eliminated from consideration since this is ascribed to the adularia→sanidine inversion. The other points of change are not to be disposed of so readily. It is conceivable that interdiffusion of the soda into the potash feldspar, as suggested by Bragg[3] for perthitic lamellar intergrowth, may be at least partially responsible for these changes in adularia. Why interdiffusion should occur intermittently at irregular temperature intervals is not clear. It is suggested here, therefore, that the thermal equilibrium diagram for the alkali feldspars is quite complex. Since such information is not currently available, the authors propose to defer consideration of this question until their study of other feldspars is completed.

ACKNOWLEDGMENT

A grant-in-aid from the Carnegie Corporation of New York which defrayed the cost of the chemical analysis is gratefully acknowledged.

[3] Bragg, W. L., Atomic Structure of Minerals (**1937**, Cornell Univ. Press), p. 241.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700
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90

Fig. 1

GRAPHICAL INTERPRETATION OF CUBIC POWDER PATTERNS

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The graphical method in common use for the interpretation of cubic powder patterns requires that measurements be made on the film and spacings calculated and plotted on a movable strip which is adjusted to a plot of the variations of the spacings with axial length. Considerable time is spent in making the calculations and plotting them, and the axial length so determined is precise only to the nearest few hundredths of an Ångstrom. If, instead of plotting the variations of the spacings, one plots the variations of the positions of the reflections on the film itself against axial length, a chart can be constructed by use of which cubic powder patterns can be interpreted by inspection. The axial length determined in this manner will be of the same order of precision as in the older method, and the time consumed in calculating and plotting spacings will be saved.

Of course, a chart constructed in this manner is useful only for films made with a specific wave-length and in a camera of a specific diameter. The chart reproduced to the correct scale in Fig. 1 is designed for patterns made with copper $K\alpha$ radiation in a camera of the type described by Buerger[1] and having a diameter of 57.26 millimeters. By appropriate photographic enlargement or reduction, Fig. 1 may be adapted to any wave-length or camera diameter.

In use the chart is placed on a viewing stand or other suitably illuminated table. The film is placed on the chart and moved up or down until every line on the film matches one on the chart, with the exception of certain high order reflections of low multiplicity which have been omitted for the sake of clarity. Because of lattice type or crystal structure requirements, certain lines on the chart may be missing on the film, but every line on the film must be on the chart, except as noted above. The agreement must, of course, occur along the center line of the film, and it is wise to rule a center line with a soft pencil.

When an agreement has been found between the lines on the film and the chart, the length of the axis to the nearest few hundredths of an Ångstrom may be read from the position of the center line of the film along the ordinate of the chart. The indices of the reflections are indicated at the edge of the chart.

[1] Buerger, M. J., *Am. Mineral.*, **21**, 11 (1936).

NOTES AND NEWS

FURTHER NOTES ON THE ADSORPTION OF MALACHITE GREEN BY SOME CLAY MINERALS

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In a recent note (1) on this subject I drew attention, among other things, to the fastness of the dye taken by certain clay minerals, and also to the varying amounts of the staining compound adsorbed. Since then my attention has been drawn to a comprehensive paper by Faust (2) on the staining of clay minerals. This is one of the most detailed papers published and deals fairly extensively with the technique of staining. Hauser and Leggett (3) describe the color reactions between amine compounds and various clays. Some of the clays used in the latter research are undoubtedly mixtures of minerals, so that the results may not be sufficiently discriminating for microscopic work. However, it is with the quantitative aspect that I am more concerned and in this note some results are given, which although incomplete suggest a fertile field of research. All the tests described here were done on the raw clay minerals, but Professor S. J. Shand, in a private communication, suggests combining staining with partial dehydration of the clay minerals. In view of the differing thermal behavior of kaolinite, montmorillonite, anauxite, etc., this method may be useful. Active service prevented any experimental work in this direction.

Technique Used in This Investigation

Aqueous solutions of 0.01 to 0.05% of malachite green were used throughout the work. The minerals were stained at ordinary room temperatures, and were carefully washed to remove all excess stain for qualitative work. In all the quantitative work, loose grains of varying sizes from 200 to 10 microns in diameter were used. In the qualitative examinations thin sections of previously stained chips were examined, but size separates from mechanical analyses formed the bulk of the material studied. The six separates after drying at 110° C. were mounted in kollolith or oils. Note that unlike the aqueous amine staining reactions, *drying does not alter* the color. Only thermal destruction of the malachite green at temperatures in excess of 600° C. can remove the color. In fact as far as can be ascertained, in the case of certain of the clay minerals the reaction between malachite green and the aluminum silicate hydrates is irreversible.

In the quantitative investigations, 10 cc. of 0.05% solution were added to 1 gram of the sample and allowed to remain in contact for varying periods, with constant stirring. The supernatant liquid was then decanted on to a very fine filter paper (Whatmans 541) and the concentration determined colorimetrically. If the stained particles were to be examined microscopically they then were thoroughly washed with hot distilled water until free from stain. In this manner the amount of dye adsorbed could be determined and its effect on the optical properties noted.

QUANTITATIVE DATA

1. *Montmorillonite*

A swelling type of montmorillonite fraction, obtained from a South African clay, was one sample studied in detail. This sample had been previously purified by sedimentation by Professor G. H. Stanley. The specimen which was a rather dirty green in color was freed from particles greater than about 40 microns and exhibited the characteristic swelling on the addition of water. Its powers of decolorizing were noted to be very high. The chemical composition was found to be as follows:

SiO_2	55.45
Al_2O_3	11.47
Fe_2O_3	8.60
TiO_2	0.06
MnO	tr.
CaO	0.85
MgO	2.97
Loss on ignition	12.46
H_2O-	7.42
	99.28

Analyst V.L.B.

The relationship between adsorption and time is shown in the curve, Fig. 1. The concentration of the filtrate decreases rapidly in a few minutes. The reaction velocity even in the case of large particles is very high. In addition, this clay is capable of decolorizing very strong solutions in a short time. Even coarse particles of this montmorillonite are capable of strong adsorption.

2. *Kaolinites*

The kaolinites studied adsorbed far less malachite green but held it just as strongly. In fact it is a characteristic of kaolinite and the bentonitic minerals, that the dye is fast. Some of the minerals studied, notably anauxite and pyrophyllite, exhibit these properties to a smaller extent. Pyrophyllite is quite a common constituent in certain residual clays and the specimen about to be discussed was possibly contaminated by it.

A white residual kaolin from the Eastern Cape Province was analyzed mechanically. The "fine sand" fraction was very uniform in size and was used in the stain tests. The composition was found to be as follows:

SiO_2	78.00
Al_2O_3	14.70
Fe_2O_3	1.37
TiO_2	1.59
MnO	nil
CaO	0.30
MgO	nil
Loss on ignition	4.30
	100.26

Analyst V.L.B.

Using a 0.05% solution as before and an adsorption period of ten minutes, the sample was found to take up 0.0068 gram of malachite green per 1 gram of clay, i.e. about 32% of the dye added was adsorbed. Under the microscope the aggregate was found to be stained a rather greenish-blue and only a few of the particles took the dye, becoming slightly pleochroic. Numerous platy and fibrous minerals of refractive index greater than 1.54 were noted which did not stain at all. Another point observed was that many grains stained differentially, i.e. the intensity of the dye varied in the same grain. In fact particles were observed which were not stained at all on one side and were greenish-blue on another.

A fine, white, powdery kaolin from Natal was also examined. This clay exhibited the rather rare phenomenon among specimens of its type of changing color upon the addition of water. The clay changed from a fairly flat-white to a creamy-yellow on damping. The chemical composition was found to be as follows:

SiO_2	49.88
Al_2O_3	33.47
Fe_2O_3	2.73
TiO_2	1.30
MnO	nil
CaO	0.55
MgO	0.04
Loss on ignition	12.82
	100.79

Analyst V.L.B.

As this material was to be tested for industrial use the procedure was to employ the entire sample in the experiment, and not any sized portion. A size analysis by pipette and sieves gave:

Size in microns	*Per cent by weight*
>589	0.5
589–200	2.9
200– 88	3.0
88– 74	4.2
74– 61	1.4
61– 43	1.6
43– 31	0.6
31– 16	80.0
16– 11	2.3
< 11 (by difference)	2.71
Moisture at 110° C.	0.79
	100.00

The absence of colloidal material will be noted. In fact South African kaolins are remarkable for their high proportion of crystalline kaolinite and absence, or negligible amount, of colloids present. In the coarser fractions of this clay there was abundant kaolinite, some muscovite and quartz, pigmented by small amounts of limonite. Using the same adsorption conditions the following results were obtained:

Time in mins.	Concentration of filtrate % malachite green
1	0.0078
5	0.0055
10	0.0039
60	0.0037
120	0.0035

The rapidity of the reaction will be noted again. Over 90% of the dye is adsorbed in ten minutes.

3. *Pyrophyllite*

A white, flaky specimen from North Carolina was obtained and as can be seen from the analysis was very pure, a fact confirmed by microscopic examination.

The malachite green stained it sky-blue. On drying, the color is not altered but immersion in kollolith imparts a distinct bluish-green color, very similar to kaolinite. The particles show no distinct pleochroism and exhibit aggregate polarization.

SiO_2	65.74
Al_2O_3	27.71
Fe_2O_3	0.21
TiO_2	0.41
MnO	nil
CaO	0.12
MgO	0.02
Na_2O	0.60
K_2O	0.18
Loss on ignition	4.90
H_2O-	0.29
	100.18

Analyst V.L.B.

It should be noted, as in the other two cases of kaolinite and montmorillonite, the color of the stained particles can be changed from blue to red on the addition of any acid, such as hydrochloric (i.e. shades of either color depending upon the mineral), and vice-versa on adding alkali. These reactions can also be effected on the dried aggregates by the fumes of ammonia or hydrochloric acid. Furthermore there does not appear to be a limit to the number of times these operations can be performed.

4. *Massive Sample of Montmorillonite*

A specimen of a pure white, massive montmorillonite was obtained from Arizona. A partial and rather rough analysis is given below. The alumina was determined directly by the 8-hydroxy-quinoline method.

SiO_2	49.48
Al_2O_3	8.28
Fe_2O_3 TiO_2	9.82
CaO	2.16
MgO	6.32
Loss on ignition	8.68
H_2O-	17.42
	102.16

Analyst V.L.B.

The sample becomes uniformly dark blue on staining. The mineral after this treatment does not exhibit pleochroism, and on acidifying becomes a deep salmon-red. The specimen did not adsorb as much malachite green as the swelling variety, the actual amount being 0.0074 gm. per gm. of sample.

REMOVAL OF EXCESS MALACHITE GREEN

One specimen after staining was washed continuously for five days with hot distilled water and the filtrate still contained small amounts of the dye. The conclusion was reached in this case that the material under examintaion was yielding again the malachite green, but at a very much slower rate than it adsorbed the dye. The chemical composition was found to be:

SiO_2	88.70
Al_2O_3	7.40
Fe_2O_3	2.16
TiO_2	tr.
MnO	nil
CaO	0.26
MgO	0.11
Loss on ignition	1.64
	100.27

Analyst V.L.B.

This sample was a "fine sand" fraction from a residual, dirty kaolin (specimen D. 88) from the Grahamstown district, Cape Province. It contained much free silica in the form of quartz, but this did not take the stain, not even along the cracks.

QUALITATIVE DATA

Besides the quantitative data described above, more than a hundred stained aggregates have been mounted and examined. Thin sections of the harder clays have been prepared, and in each case a stained and unstained section were compared microscopically. Some qualitative and quantitative work was also done on the light absorption, before and after staining. Attention was paid in particular to the blue and violet end of the spectrum.

CONCLUSIONS

In most cases the remarkable fastness of the dye is noteworthy. The stability of it is great and stained particles can be heated and mounted in resins without difficulty. The stained particles can also, after drying, be examined by immersion in the oils described recently (4).

A considerable amount of work remains to be done on these minerals. Illite, dickite, and auxite have only been subjected to cursory examination and so far no data is available for nontronite and the ferruginous clay minerals. Illite was found to be present in one of the specimens of kaolinite, but only in small quantities.

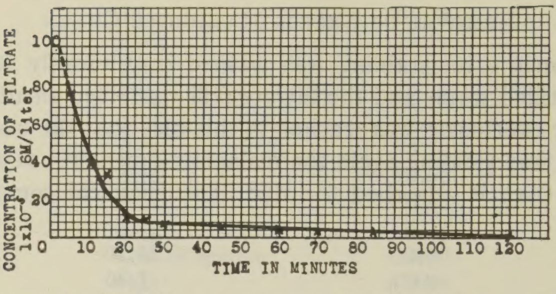

FIG. 1. The concentration of the malachite green in this experiment was 0.025 per cent. 100 cc. were added to 0.5 gm. samples. Small samples of clay had to be used as the amount of material was small. It will be noted that 99.9 per cent of the dye is adsorbed at the end of two hours.

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HELIUM RETENTIVITIES OF MINERALS

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About four years ago the writer commenced critical researches to determine the limitations of the helium-radioactivity method of age determination. The first results on separated minerals from rocks disclosed the important fact that some minerals do not retain all of the helium generated within their structures during geological time.[1]

It was suggested that "it might prove advisable to direct future work to certain unaltered minerals from rocks" and that if, as indicated by the two cases presented at the time, "feldspars permit the escape of helium, absolute helium age determinations will be obtained only from certain minerals." Similarly, in a theoretical investigation[2] it was recommended that the best crystalline material available be studied, since in the absence of alteration and crystal imperfections, "ages obtained on carefully selected minerals should not differ from the true values by more than the present experimental errors of measurement." These latter were the subject of an investigation following the experiments on separated minerals.[3]

Since the preparation of these papers, more than a hundred age determinations have been made by the writer. The results on minerals separated from fifteen different rocks have confirmed the earlier conclusions and have given an idea of relative helium retentivities of different minerals. A brief summary of results is presented herewith, and when time permits, the data will be discussed in greater detail.

The ability to retain helium varies from mineral to mineral. All of the feldspars investigated by the writer were found to have lost more than half of their helium, sometimes more than ninety per cent. On the other hand, certain minerals with close-packed structures such as magnetite and unaltered pyroxenes and amphiboles, appear to retain helium. Quartz showed variable retentive properties, the least loss being found in younger unmetamorphosed granites. Preliminary average retentivities, calculated from the relative retentivities combined with geological and reliable radioactivity age data are as follows: feldspars, $\frac{1}{4}$; quartz, $\frac{1}{3}$; mica, $\frac{1}{2}$; rocks, $\frac{2}{5}$; pyroxenes, $\frac{3}{4}$; hornblende and magnetite, about 1. The actual helium retentivity of one type of mineral may, however, vary over fairly wide limits. The changes in retentive properties from mineral to mineral, and even in the same mineral under similar conditions, explain some apparently spurious helium values found for rocks in the writer's laboratory and elsewhere.[4,5,6]

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Some measurements after various mechanical and thermal treatments of rocks over periods of time, have indicated a surprising degree of retention of helium, while others have shown a pronounced loss. Some of these discrepancies can be traced to differences in the mineral assemblages and in the geological histories of the rocks.

While some ferromagnesian minerals and magnetite yield results which seem to approximate the true age most closely, some evidences of excess helium, whether original magmatic helium or otherwise, have been found in these minerals, so that even these age results must be interpreted with care.

To get the most from helium-radioactivity studies, detailed investigations of the separated minerals should be made, but in many cases the geochronological problem does not require such effort. The type of specimen to be studied, the type of problem to be solved, often suggests a simpler approach. With the data accumulated in the writer's laboratory it has been found that the helium index of the rock is sometimes sufficient, at least for the initial approach, although in other cases studies of specific unaltered minerals are necessary.

These researches have been supported by Mr. Hans Lunaberg and the Viking Foundation.

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Dr. Kenneth K. Landes, Professor of Geology at the University of Kansas since 1933 and Director of the Kansas Geological Survey, has been appointed Chairman of the Department of Geology, at the University of Michigan.

Any one having suitable material in preparation for the Journal is urged to complete the article and mail it to the Editor before departing for summer field work. Only in this way can the service of the Journal be maintained without interruption during the summer and fall months.